COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

March 1957

Night view of Kaiser Aluminum and Chemical Corp.
Chalmette, La., plant (see p. 45)

Dynamics of Boiler Control

Industrial Power Developments

The 1957 Nuclear Congress

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

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March 1957

Feature Articles

Editorials

Departments

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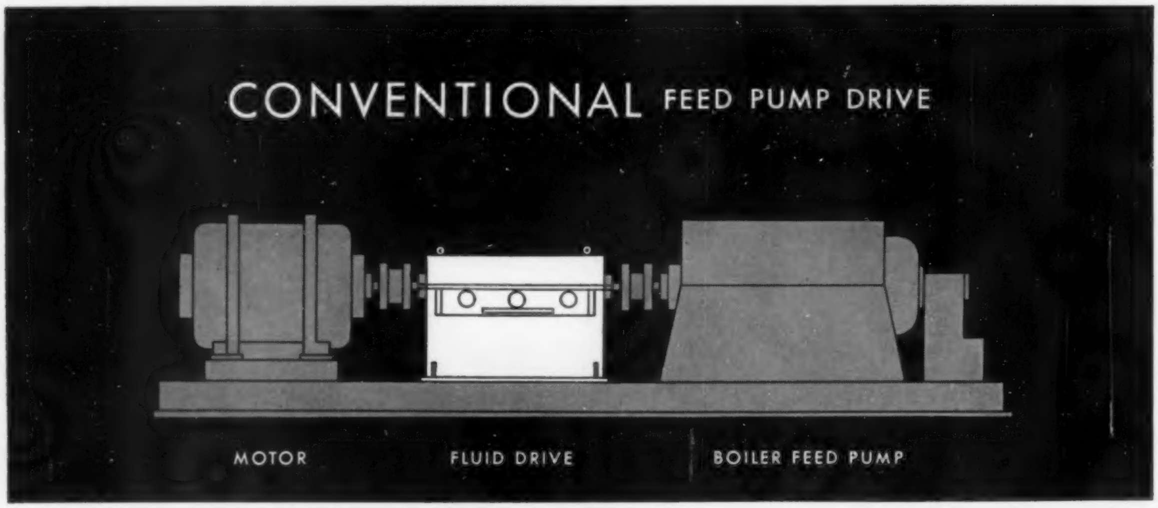
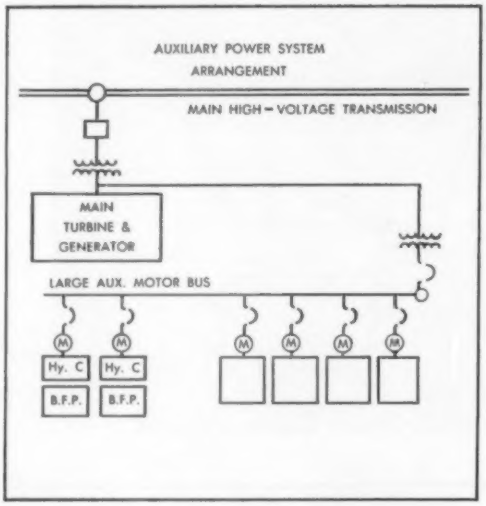
BPA

Printed in U. S. A.

How *Gýrol*® Fluid Drive meets all

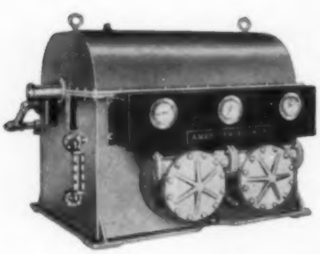




Of all power-plant auxiliaries, the boiler feed pump consumes the greatest single segment of invested power. To release more of this power to consumer lines, power plants of all sizes are controlling feed water flow by speed regulation through Gýrol Fluid Drive – driven by a constant speed prime mover.

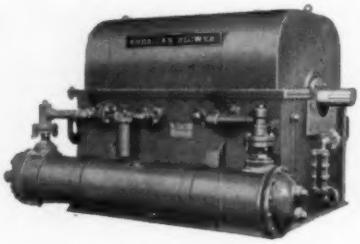
Gýrol Fluid Drive offers several specific advantages:

1. It saves power over the entire operating range by eliminating wasteful throttling by valves.
2. Fluid Drive's adjustable-speed feature permits reduction in pressure – resulting in further power savings.
3. It reduces wear on bearings, and other vital pump parts, by letting the pump operate at speeds that fit boiler demands.
4. With Fluid Drive, paralleling of pumps is simplified. Change-over from operating to standby pump is quick and easy.
5. Quiet operation is inherent in the design of Fluid Drive, since a "cushion of oil" is the means of energy transmission.



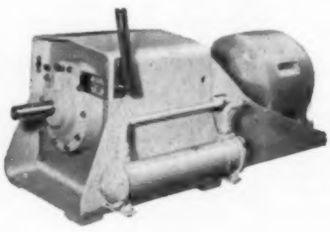
TYPE VS CLASS 6

- adjustable speed control
- 250 to 12,000 horsepower
- speeds to 3600 rpm



TYPE VS CLASS 4

- adjustable speed control
- 100 to 2500 horsepower
- speeds to 1800 rpm

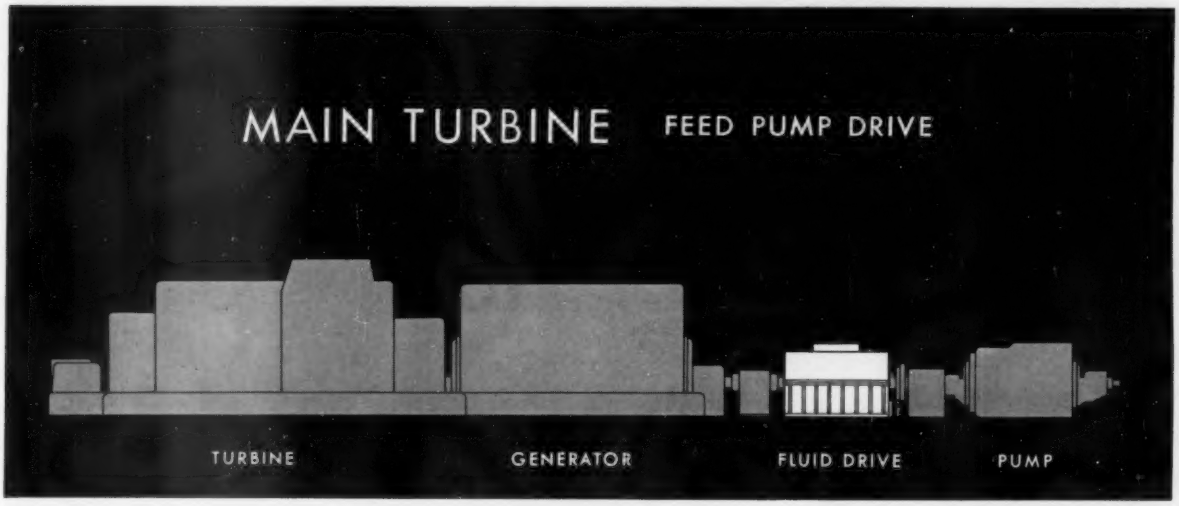


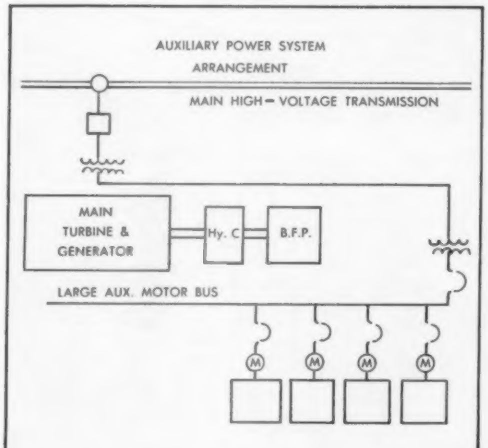
TYPE VS CLASS 2

- adjustable speed control
- 1 to 800 horsepower
- speeds to 1800 rpm

requirements for feed pump control

Regardless of station size, arrangement, or prime mover, you get the advantages of power savings, reduced pressures, and quiet operation with American Blower Gýrol Fluid Drives





Already in the construction stage is the use of Gýrol Fluid Drive for main turbine feed pump drives on some of the largest generating units yet projected.

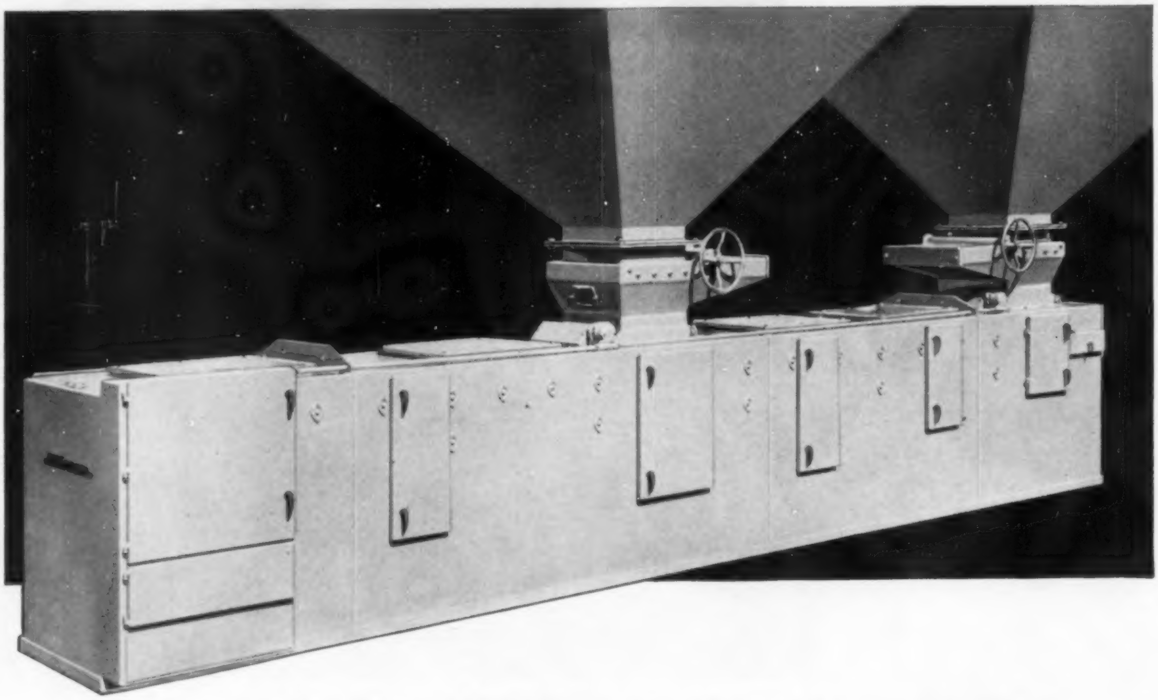
For example, two of these stations will each drive, through a 12,000-hp adjustable-speed Gýrol Fluid Drive, the main feed pump from the high-pressure turbine. Full boiler capacities will be supplied by the single 5-stage pump, each delivering 6330 gpm against 6400 feet total discharge head when operating at 3510 rpm with feed water at 363° F.

Each pump requires an excess of 11,000 hp, and will be driven from the generator shaft through an adjustable-speed Gýrol Fluid Drive.

In your plans for expansion, why not discuss the advantages of Gýrol Fluid Drive with an American Blower engineer. His knowledge of this application in modern power plants may prove valuable to you. Call our nearest branch, or write: American Blower Division of American-Standard, Detroit 32, Michigan. In Canada: Canadian Sirocco products, Windsor, Ontario.

AMERICAN BLOWER

Division of American-Standard



This Stock Equipment Company *Long Center* Scale Was Built to Order

Stock Equipment Company has specialized in Bunker to Pulverizer Feeder Equipment for over 25 years. During that time, every piece of S-E-Co. equipment has been designed and built for a specific application and installation. It is this specialization, plus great attention to detail, that makes the difference between merely satisfactory operation and trouble-free, dependable, accurate S-E-Co. operation.

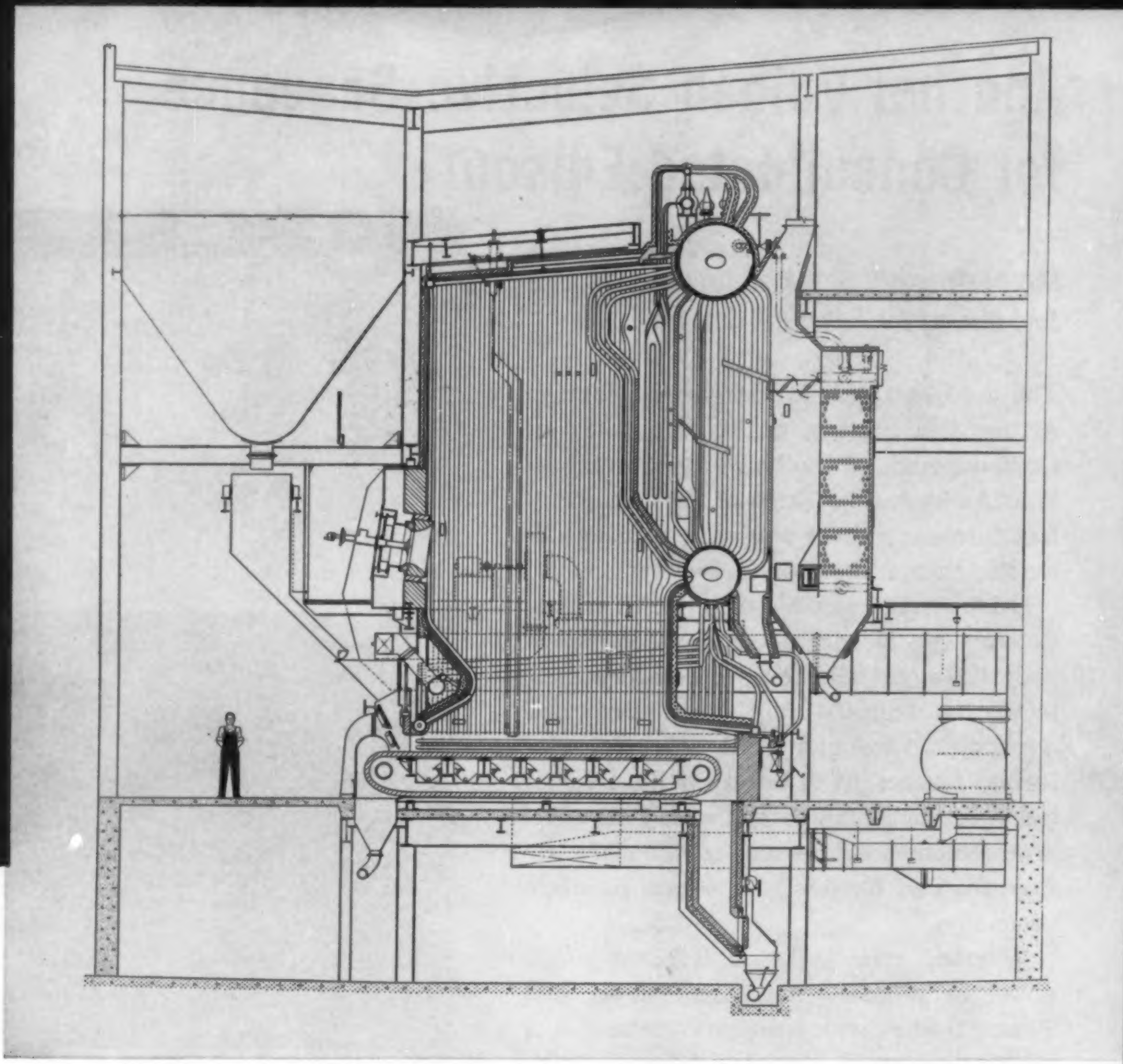
When you order a S-E-Co. Coal Scale, Coal Valve, Coal Distributor, Paddle Type or the new Turn Counting Type Coal Stoppage Alarm, you know that it will be custom built especially for you. From the inquiry through to the actual installation, Stock Equipment Company works with you to make sure that the job is done properly so that you get the utmost in service out of your equipment.

Of course, this kind of planning and follow through costs more, but you will find that the reliability and long, trouble-free life is worth far more than the extra cost involved. If you are designing or building a new power plant or enlarging or modernizing an old one, take advantage of available information on the best in Bunker to Pulverizer Feeder Equipment by writing Stock Equipment Company, 745 Hanna Building, Cleveland 15, Ohio.

SPECIALISTS IN
BUNKER TO PULVERIZER AND
BUNKER TO STOKER EQUIPMENT

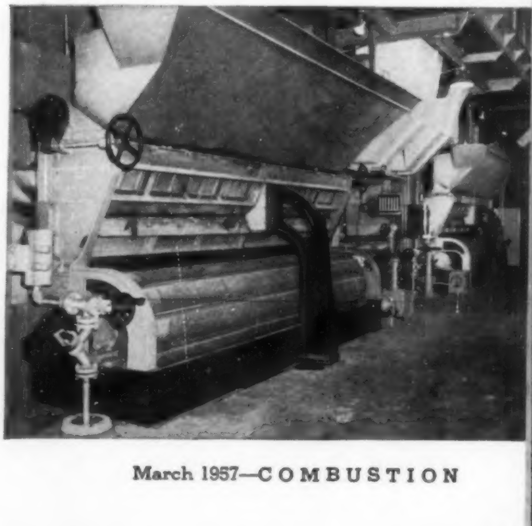
STOCK Equipment Company

CLEVELAND 15, OHIO



Cross-sectional elevation of the C-E Vertical Unit Boiler, Type VU-50X, installed in the Mill Division Plant of the Central Fibre Products Company, Quincy, Illinois. There are two units, each fired with a C-E Traveling Grate Stoker and designed for the future use of oil or gas as alternate fuels.

Present operating conditions are 185 psi and 450 F. Each unit has a maximum continuous capacity of 85,000 lb per hr and a four hour peak of 100,000 lb per hr. The boilers are designed for 650 psig and in the future will operate at 610 psig and 650 F.



Firing aisle at the Central Fibre Products Mill Division plant at Quincy, Ill. This is a front end view of two C-E Traveling Grate Stokers which fire the VU Boilers as shown by the cross-sectional elevation drawing.

Here's what makes Walworth Bronze Valves *the* real bargain!

TYPICAL OF WALWORTH QUALITY is the union body-to-bonnet connection which stiffens the body against internal pressure; makes taking the valve apart a simple operation and reduces the chances of distortion or leakage even though the valve is repeatedly taken apart and reassembled. With this type of construction there is no possibility of the bonnet coming off the valve while the handwheel is being turned.

HEAVY BODY CONSTRUCTION is typical of *all* Walworth Bronze Valves. Extra-thick walls and rugged wrench hexes constitute a high safety factor and prevent distortion while the valve is being installed in the pipeline. Extra-deep pipe threads are accurately machined to eliminate leakage. Walworth Bronze Valves are also available with flanged, silver-brazed or soldered ends in certain sizes and types.

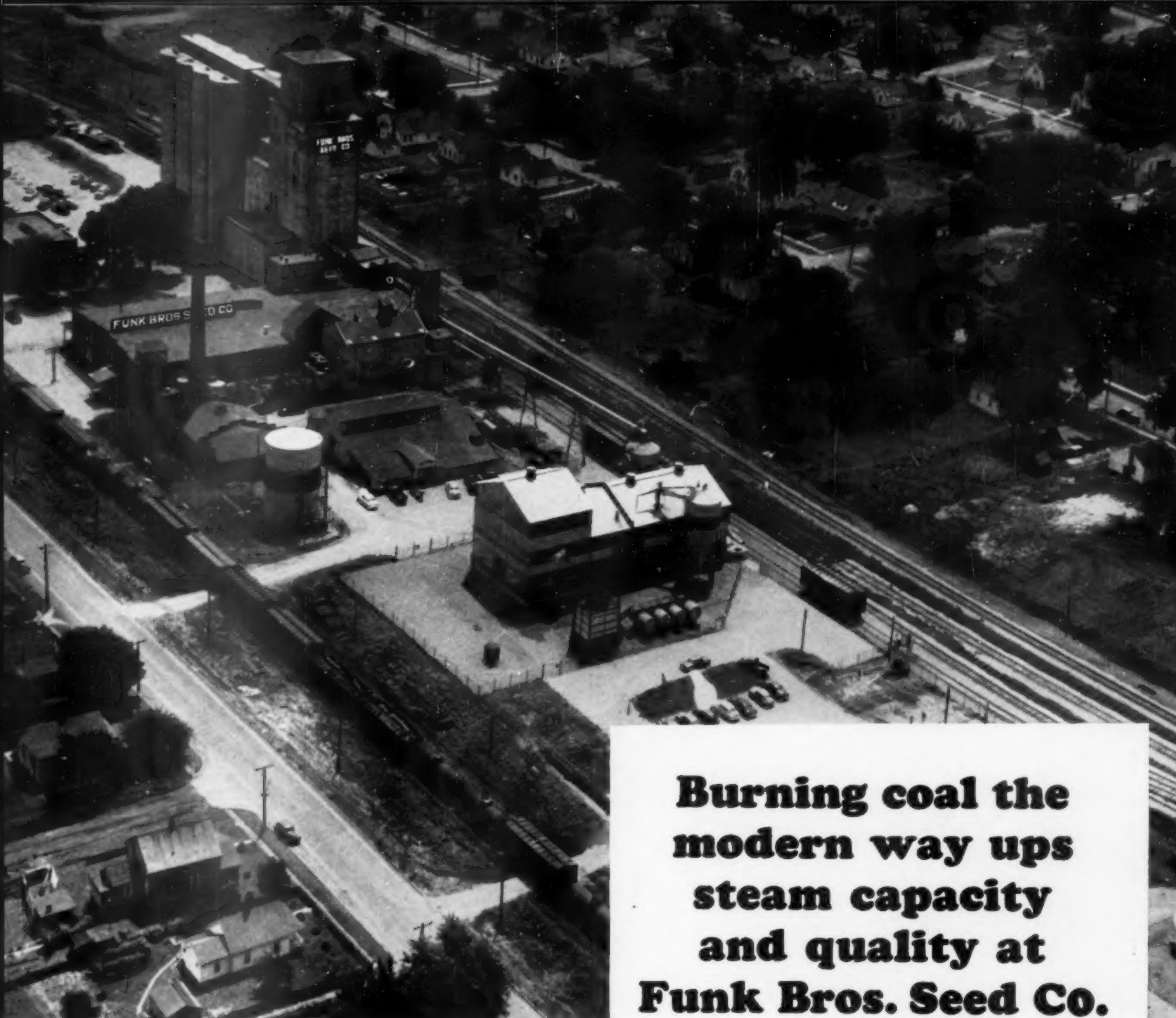
EXTRA-LARGE STEMS with extra-long, extra-deep threads prolong valve life, protect against wear and distortion and provide tight positive shutoff. The surface of the stem is machined to a glass-like finish for minimum handwheel effort and to preserve the packing which results in fewer inspections and less maintenance. The top of the stem is tapered and squared to hold the handwheel securely.

TO REDUCE WIRE DRAWING to a minimum, certain types of bronze globe valves have stainless-steel plug-type seats and discs heat-treated to a nominal hardness of 500 Brinell, adding years to valve life even in severe services. These valves can be tightly closed on sand, grit or pipe scale without damage. Seats and discs are machined simultaneously, assuring perfect mating.

There is a Walworth Bronze Gate, Globe, Angle or Check Valve for every service. Walworth is continually developing new valve types and materials, including plastics, to keep pace with the growing variety and severity of services in modern industry. For full information, see your Walworth Distributor or write: *Walworth, 60 East 42nd Street, New York 17, N.Y.*

WALWORTH

Bronze Valves and Fittings



Burning coal the modern way ups steam capacity and quality at Funk Bros. Seed Co.

Consult an engineering firm

Designing and building hundreds of heating and power installations a year, qualified engineering firms can bring you the latest knowledge of fuel costs and equipment. If you are planning the construction of new heating or power facilities—or the remodeling of an existing installation—one of these concerns will work closely with your own engineering department to effect substantial savings not only in efficiency but in fuel economy over the years.

facts you should know about coal

In most industrial areas, bituminous coal is the lowest-cost fuel available • Up-to-date coal burning equipment can give you 10% to 40% more steam per dollar • Automatic coal and ash handling systems can cut your labor cost to a minimum. Coal is the safest fuel to store and use • No smoke or dust problems when coal is burned with modern equipment • Between America's vast coal reserves and mechanized coal production methods, you can count on coal being plentiful and its price remaining stable.

As Funk Bros. Seed Co., Bloomington, Ill., increased the capacity of its soybean extraction plant 50%, the firm's old steam plant proved inadequate. Not only was it unable to produce enough steam, but steam quality was not suitable for best processing conditions. To remedy this situation, the company installed a new 26,000 lbs./hr. boiler, automatic controls, automatic coal and ash handling system and related equipment.

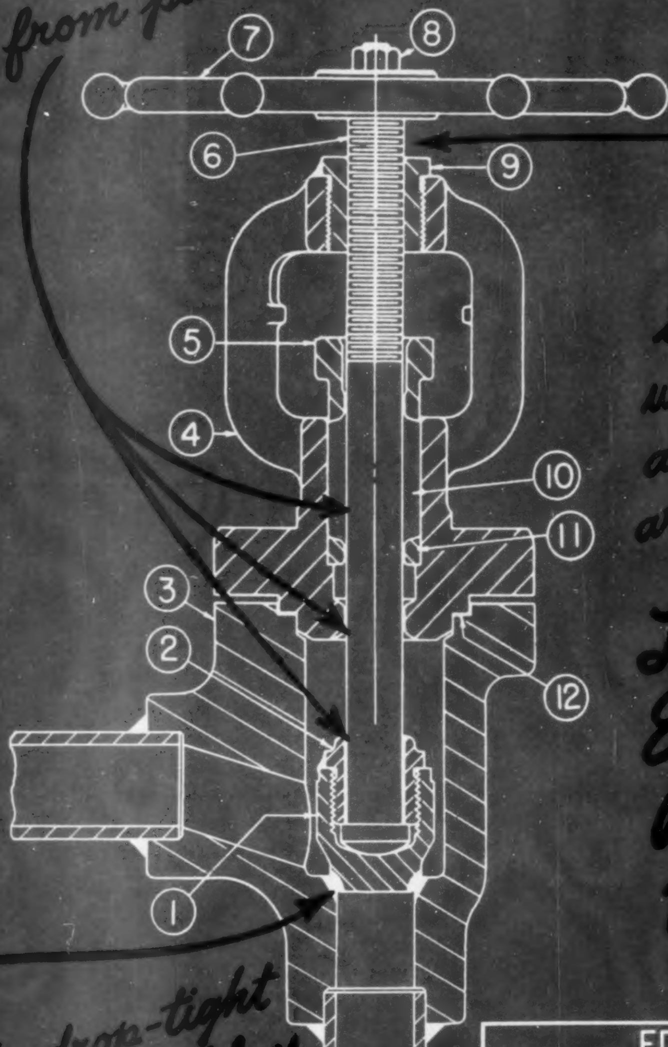
Today the steam plant at Funk Bros. requires only one man per shift, holding one of the most attractive operating jobs in the plant. Evaporation rates are in excess of 9 lbs. of steam per lb. of coal and there is adequate high quality steam for further expansion requirements. Also cleaner plant conditions resulting from this modernization have greatly improved community relations.

For further information or additional case histories showing how other plants have saved money burning coal, write to the address below.

BITUMINOUS COAL INSTITUTE
Southern Building • Washington 5, D. C.

Deep packing chamber-dependable backseat assure freedom from packing problems.

Edward Acme form threads are easy to operate at all pressures.



Gadgety designs with internal packing and sliding contacts are potential headaches-

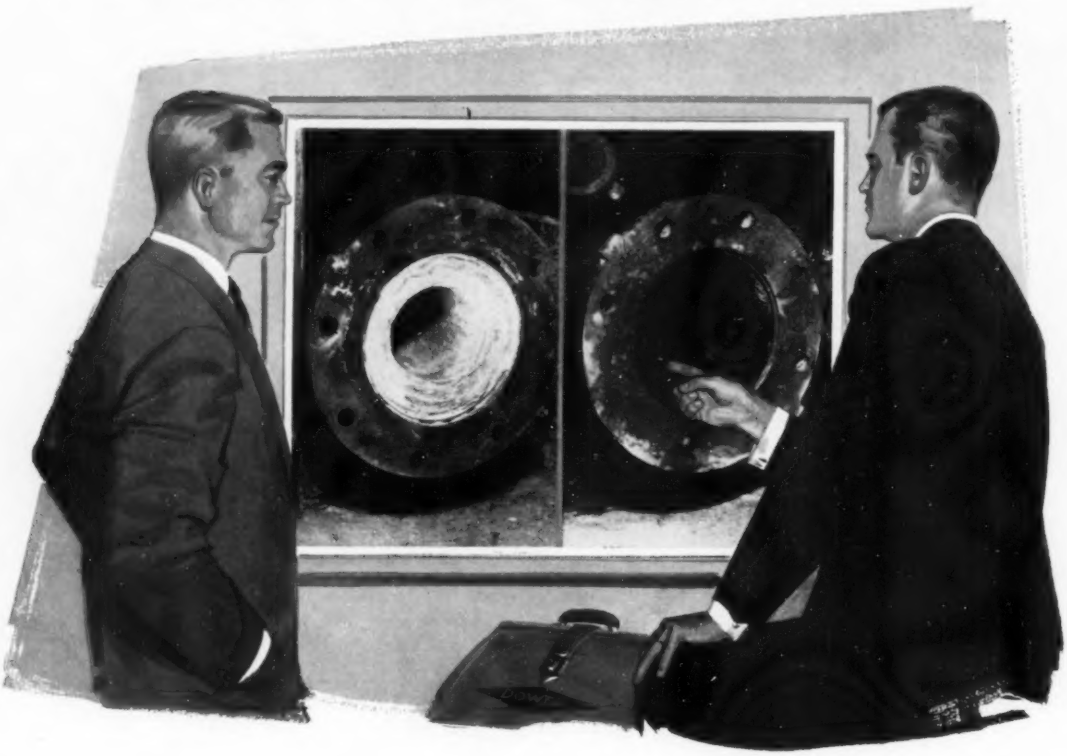
Let's Request Edward Blow-Off Valves

Two drop-tight Blow-Off Valves are better than one-permits repair without shutdown-gives piping flexibility-parts are interchangeable.

EDWARD VALVES, INC.		
SUBSIDIARY OF ROCKWELL MANUFACTURING CO.		
EAST CHICAGO, INDIANA		
1500 lb. FORGED STEEL BLOW-OFF VALVES		
DRAWN [illegible]		DRAWING №
CHK'D. [illegible]		AE-3664-1
APPD. [illegible]	DATE 8-29-55	

Edward builds Globe and Angle Stop, Non-Return, Stop-Check, Check, Gate, Blow-Off, Mudline, Relief, Hydraulic, Instrument, Gage, and Special Valves and Strainers.

here's how Dowell chemical cleaning saved $71,000 and helped protect a plant profit!



A few months before their peak season, the operators of this plant decided their main water line might not supply the water necessary to meet peak demands. The line was cast-iron, 16-inches in diameter and over 7,000 feet long. Its original flow efficiency or "C" factor had been 105; scale build-up had reduced this to 72. To lay an auxiliary line would cost at least $85,000.

Dowell contracted to clean the pipe chemically for a little less than $14,000, and to restore a minimum of 50 per cent of the line's lost capacity.

This Dowell did, and more—increasing the "C" factor to 92! Enough water was immediately available for capacity operation. This saved the plant $71,000 and helped protect the company's annual profit.

The operating credit realized by this food processing plant, as a result of Dowell service, is similar to those realized by other Dowell customers—in the steel, paper, chemical, oil refining, power and allied industries.

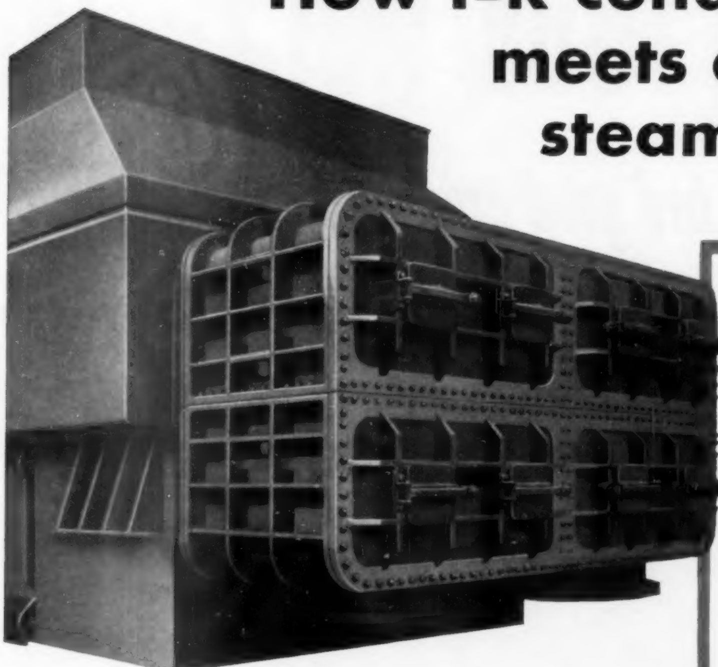
Dowell engineers are experts in the use of solvents to remove scale and sludge—deposits that cut the throughput of product, process and steam generating systems. Dowell does the job, furnishing all chemicals, trained personnel, pumping and control equipment.

For specific information on how chemical cleaning can help you to greater profits, call the Dowell office nearest you. Or write Dowell Incorporated, Tulsa 1, Oklahoma.

Have Dowell clean it chemically DOWELL

A SERVICE SUBSIDIARY OF THE DOW CHEMICAL COMPANY

How I-R condenser design meets all of today's steam plant needs



...Sets the pace in turbine-condenser adaptability

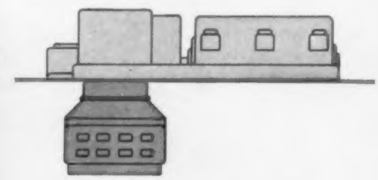
Permitting variations in condenser length, width and height without sacrificing performance, the Ingersoll-Rand rectangular design proves readily adaptable to all steam plant needs. Dimensional proportions can be changed over wide limits without departing from the basic standard arrangement of internal elements. This means maximum utilization of the condenser space available.

Continued refinements in I-R design are contributing to ever smaller space requirements for a given condensing capacity. These developments conform with the modern trend to higher turbine efficiencies and more compact turbine designs in reduced foundation areas for a specified kw rating.

Your I-R engineer will be glad to give you further information and submit recommendations to meet your particular requirements.

Ingersoll-Rand
4-487 11 Broadway, New York 4, N.Y.

COMPRESSORS • TURBO BLOWERS • ROCK DRILLS • AIR TOOLS
CENTRIFUGAL PUMPS • CONDENSERS • GAS AND DIESEL ENGINES

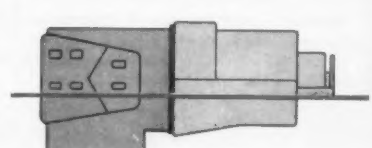


BOTTOM-EXHAUST TURBINE

Serving a 135,000-kw turbine, this condenser hcving 65,000 sq. ft. surface requires a headroom of only 14 feet 8 inches. It assures maximum economy of installation, operation and maintenance.

SIDE-EXHAUST TURBINE

Mounted on the turbine floor, the twin condenser shells of this I-R condenser are directly connected to the dual side exhausts of the cross-compound 191,000-kw steam-turbine.



AXIAL-EXHAUST TURBINE

Connecting directly to the exhaust of an axial flow exhaust turbine, this condenser of the single-pass rectangular type represents an outstanding example of I-R adaptability.

makes any boiler job easier"

ELECTRUNITE *Boiler Tubes"*

—says "Red" Thompson,

Combustion Engineering Construction Foreman

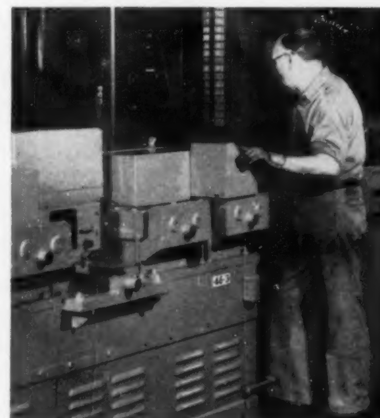
"Red" Thompson is typical of expert boiler-construction foremen all over the country. To them, uniform ductility in boiler tubes means smooth, accurate bends, easy roller-expansion and bead-over. Tight, weeper-free joints. It all adds up to easier, more economical installations.

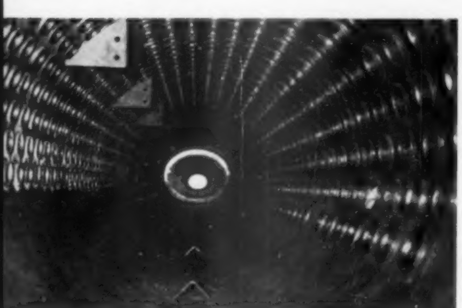
That's why they like to work with Republic ELECTRUNITE® Boiler Tubes. Every tube is uniformly ductile. But more important, Republic Tubes assure *dependability* where it counts the most: in long-term operation.

This recognition of the efficiency and dependability of ELECTRUNITE Tubes is reflected by the number of boilers everywhere that are protected with Republic Tubes. One of the more recent is this new steam generator (left) built for the city of Garland, Texas. Designed and erected by Combustion Engineering, Inc., New York, it has a capacity of 110,000 pounds of steam per hour, can operate at 476 psi. and 750° F. And there's a lot of ELECTRUNITE on the job to help provide top performance.

Successful tube performance is dependent on precise manufacturing techniques. Republic's ELECTRUNITE welding process produces an accurate, uniform, wall thickness assuring uniform heat transfer all around and throughout the length of each tube. Dependability cannot be threatened by longitudinal thin spots. Each length of tube is hydrostatically or electronically tested to conform to the applicable ASTM specification and the requirements of the ASME Boiler and Pressure Vessel Code, as well as local, state and boiler-insurance requirements. In addition, ELECTRUNITE is approved on an equal basis with tubes made by any other process up to 850° F. It is available for pressures over 2000 psi. in various sizes and wall thicknesses.

Before you specify tubes for new or existing installation, get all the facts on ELECTRUNITE Boiler, Condenser and Heat Exchanger Tubing from your local Republic Representative. Or send coupon for literature.





REPUBLIC ELECTRUNITE BOILER TUBES ALWAYS ROLL IN EASILY— thanks to the uniform ductility and concentricity throughout every inch. They slide through drum holes freely, roller-expand and bead-over to make tight, non-leaking joints.

FREE WALL CHART, entitled "Care and Maintenance of Boiler Tubing", is a handy guide for protecting your present boiler installations. Send for it today by checking and mailing coupon.

SPECIFY FARROWTEST®

Here's the most conclusive, non-destructive electronic tubing test in use today. Developed by Republic, FARROWTEST provides detector coils that can electronically spot defects in tube walls which would be hidden from routine test procedures. You can specify FARROWTEST on ELECTRUNITE Boiler Tubes instead of your present method, at no extra cost.

STEEL

and Steel Products

REPUBLIC STEEL CORPORATION
Dept. C-3510
3172 East 45th Street, Cleveland 27, Ohio

Please send
- ☐ Illustrated booklet giving facts on ELECTRUNITE Boiler Tubes
- ☐ Eight-page brochure on ELECTRUNITE Heat Exchanger Tubing ☐ Carbon Steel ☐ Stainless Steel
- ☐ Handy wall chart on care and maintenance of boiler tubes
- ☐ FARROWTEST brochure

Name__________ Title__________
Company__________
Address__________
City__________ Zone_____ State__________

Process CO_2 and Steam Needs Met on Low Grade Western Coal

with REPUBLIC *Automatic* COMBUSTION CONTROLS

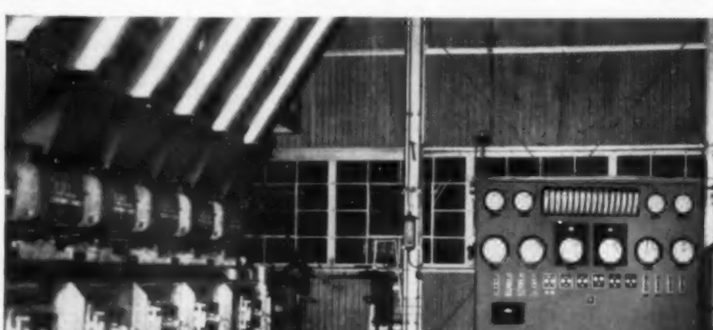
Utah-Idaho Sugar Company's new $7,000,000 sugar beet factory at Moses Lake, Washington, makes over 75,000,000 lbs. sugar each year, and uses a lot of steam and CO_2 to do it. Republic automatic combustion controls meet these multiple needs efficiently.

High CO_2 in the flue gas is an important indication of combustion efficiency, but it has added importance at the new Moses Lake plant of the Utah-Idaho Sugar Co. High CO_2 production must be maintained to assure adequate supplies of the gas for processes, and the concentration of CO_2 in the flue gas is important to the cost of its extraction.

Republic Automatic Combustion Controls keep the CO_2 at a high 12-13%, despite the low-grade western coal being burned.

The plant's spreader-stoker-fired 250,000 lb/hr boiler must be regulated to meet the CO_2 quantity and concentration requirements while furnishing the needed process steam at top efficiency. Plant operators report that the Republic controls meet these multiple requirements even during ash removal, soot blowing, and fire cleaning—without disturbing the fuel-air ratio and *while on fully-automatic control.*

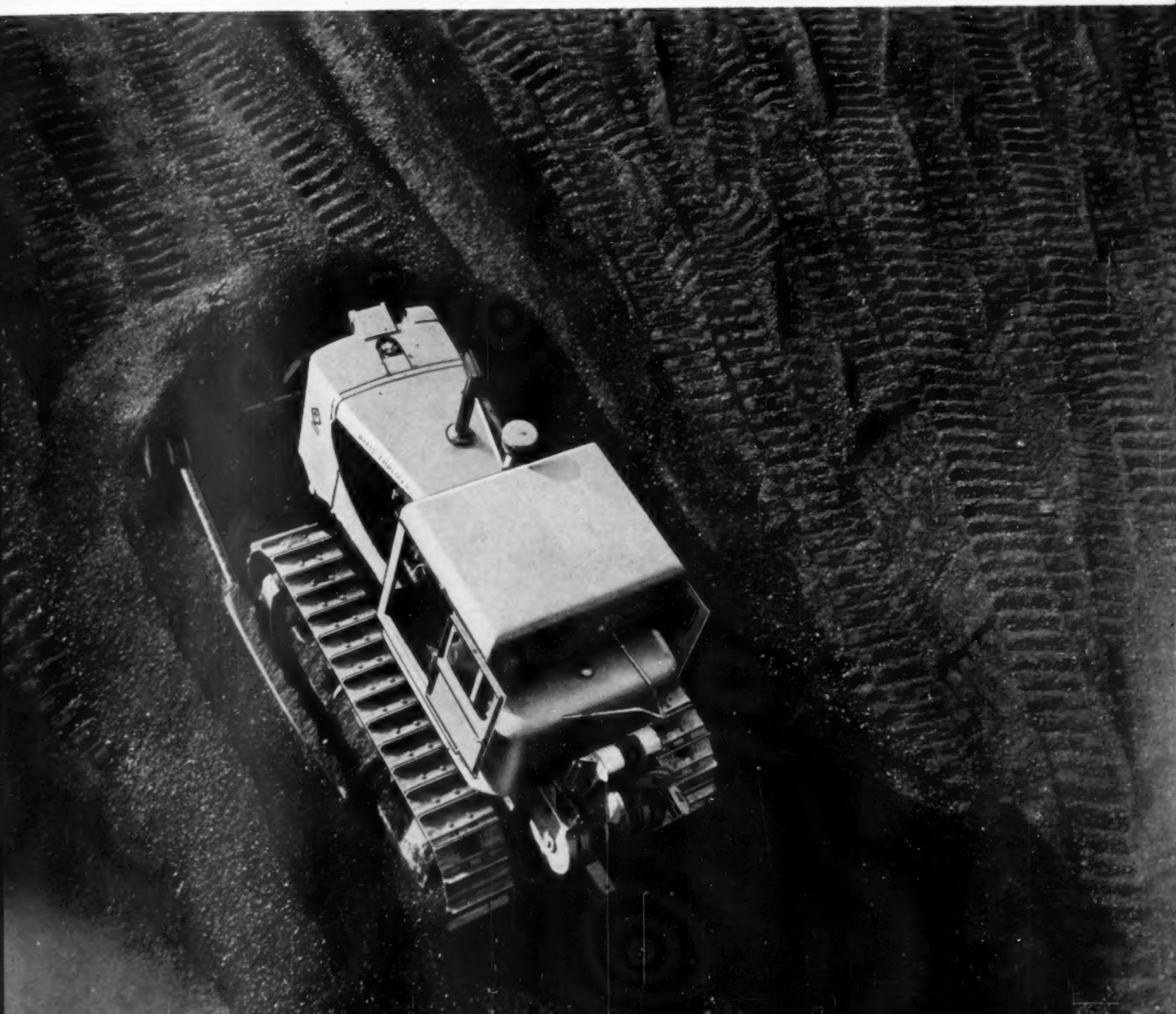
Speed-controlled forced and induced draft fans regulated by the combustion controls maintain proper draft without dampers, and despite a high stack. A three-element Republic boiler feedwater system is also regulated by the combustion controls to meet water requirements at all steaming rates.



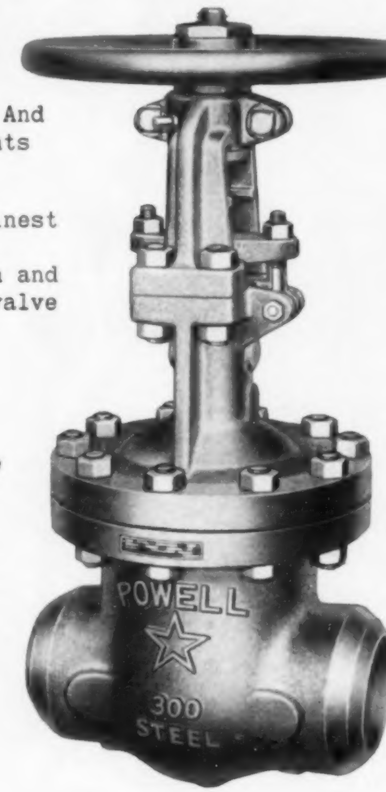
This plant is another example of how Republic combustion engineers can work to unusual and rigid specifications in designing and building combustion controls for individual requirements. To get top boiler performance and those extras that your plant needs, ask Republic to design and build your combustion control system.

REPUBLIC FLOW METERS CO.

2240 Diversey Parkway
Chicago 47, Illinois



Inside Story on POWELL VALVES for POWER PLANTS



On the outside, valves may look alike. However, on the inside there can be a big difference -- in the metal itself, in design, in manufacture. And the inside story on Powell Valves for Power Plants is that every valve has PERFORMANCE VERIFIED.

In the manufacture of Powell Valves, only the finest available materials are used. And painstaking quality control is rigidly enforced through each and every step of manufacture. Every part of every valve must pass rigid inspection.

As a final step in manufacture, every Powell Valve is subjected to an ACTUAL LINE TEST. Because of Powell's quality control, valve failure is practically unknown. Records from the world over prove it.

Consult your Powell Valve distributor. If none is near you, we'll be pleased to tell you about our COMPLETE quality line which has PERFORMANCE VERIFIED.

FIG. 3003WE -- Steel O.S. and Y. Gate Valve for 300 Pounds W.S.P.

FIG. 1561WE -- 150-Pound Steel Swing Check Valve

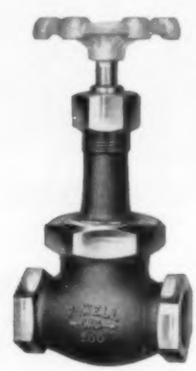


FIG. 2608 -- Bronze "W.S." Full Flow Globe Valve for 200 Pounds W.P.

PERFORMANCE
PV
VERIFIED

The Wm. Powell Company, Cincinnati 22, Ohio . . . 111th YEAR

POWELL VALVES

BRONZE, IRON, STEEL AND CORROSION RESISTANT VALVES

Unretouched photo of Nalco treated boiler at Georgia Institute of Technology, Atlanta, Georgia

Eastern Public Utility Installs Two More Koppers Electrostatic Precipitators to Remove Fly Ash

Major Utility has installed 8 Koppers Electrostatic Precipitators since 1947

YEARS of cost-saving, highly efficient performance preceded this latest installation of Koppers Electrostatic Precipitators. During these years, this leading Eastern public utility was able to judge Koppers by on-the-job operation—the most positive proof of performance.

Proves Performance on the Job

Ten years ago, this company purchased its first two Koppers Electrostatic Precipitators for fly ash removal. Satisfactory performance and low maintenance costs justified the purchase of additional Koppers units that were installed in a total of 4 stations. The eight units furnish highly effective, trouble-free operation in a varying range of CFM capacities.

Supplies a Wide Range

The eight Koppers Electrostatic Precipitators serve boilers ranging in capacity from 570,000 #/hr to 950,000 #/hr. Guaranteed efficiency runs as high as 98%, depending on the need of each application. This ability to engineer for a wide range of capacities enables Koppers to satisfy the needs of each station.

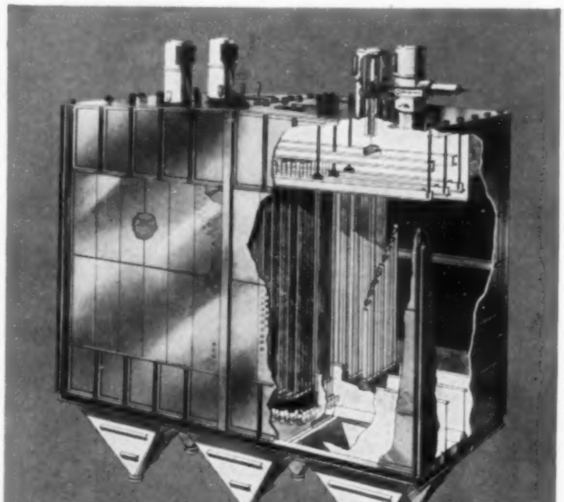
Meets Individual Plant Needs

Koppers custom-designs each Electrostatic Precipitator. Koppers units remove boiler fly ash before the flue gas is discharged from the stack. In designing Electrostatic Precipitators, Koppers utilizes its knowledge of the characteristics of various coals, types of boilers and methods of firing.

Backed by Know-How

Koppers gas cleaning experience goes back 75 years. This experience is backed up by extensive research facilities at Verona, Pa., and Baltimore, Md. From this experience and research has come gas cleaning equipment for all sizes and types of plants.

Get the most out of your gas cleaning dollar. Write KOPPERS COMPANY, INC., Metal Products Division, Industrial Gas Cleaning Dept., 4403 Scott Street, Baltimore 3, Maryland.



This cutaway photo of a Koppers Electrostatic Precipitator shows shell, vibrators, and collecting and discharge electrodes. The actual design and arrangement of elements vary widely because Koppers Electrostatic Precipitators are custom-engineered to fit the requirements of each installation.

Quarter-inch steel plate is melted with an acetylene torch, but the supporting ALFRAX® BI brick stays cool enough to be held by hand.

Refractories...for really high temperature **insulation**

The problem of heat insulation at extreme temperatures is solved by two of Carborundum's refractories:

One is made of fused alumina "bubbles" or hollow spheres, bonded and high fired. These selected bubbles give proper balance between the number of surface temperature drops and total pore space (about 65% porosity) to effectively decrease heat flow between hot and cold faces. The alumina imparts high hot strength to the finished refractory, trade-marked ALFRAX BI. Under a load of 12½ psi and a temperature of 2732° F held for 1¾ hrs., less than 1% contraction occurred. No contraction whatever developed in 5 hour reheat tests at 3092° F. This combination of properties makes ALFRAX BI refractories unique in their ability to insulate at temperatures where other materials are impractical.

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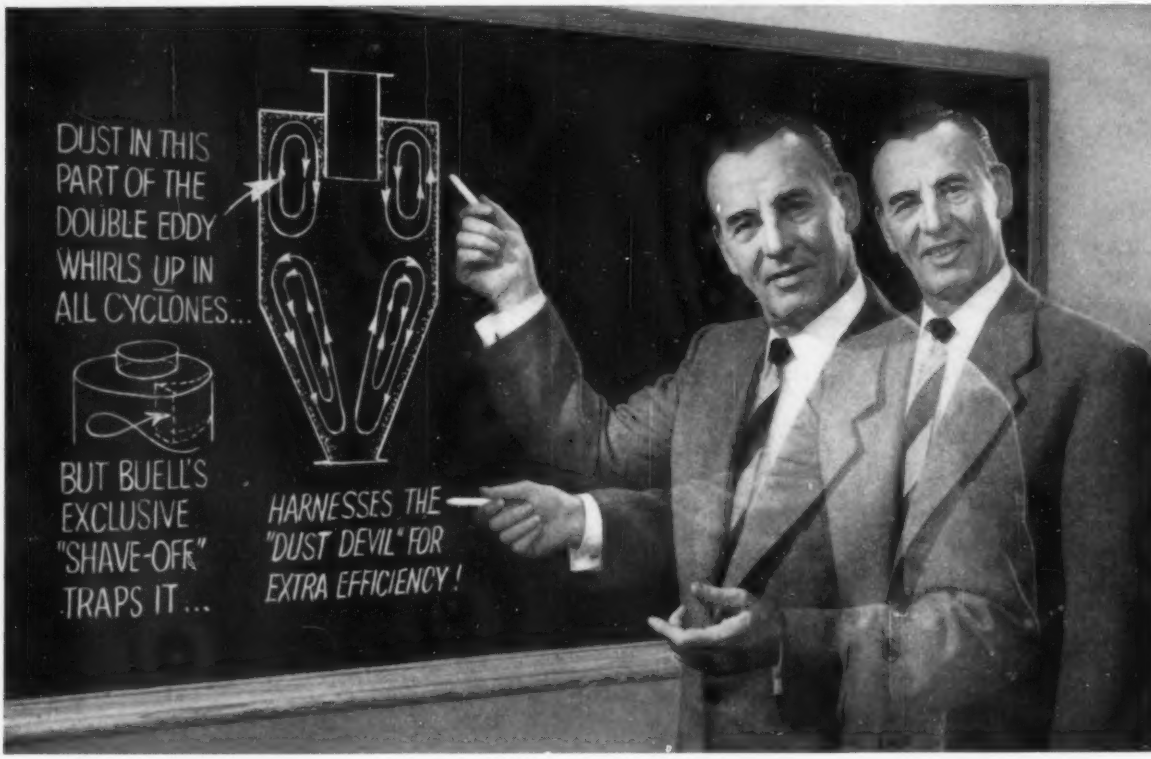

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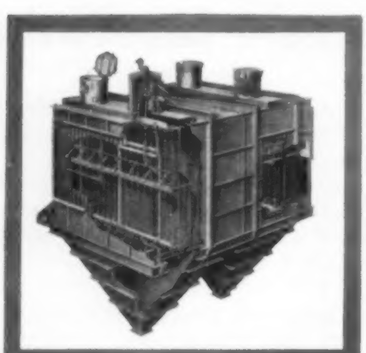

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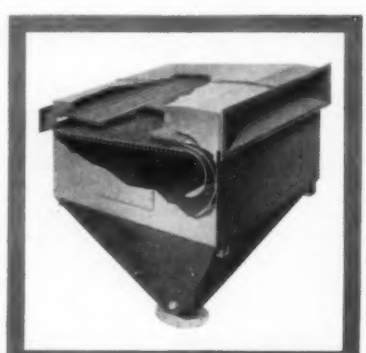

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COMBUSTION *Editorial*

It Couldn't Be Done

When announcement was made in the summer of 1945 that the first atomic bomb used in warfare had been dropped on the Japanese city of Hiroshima, public attention was directed to a new force of nature. The extent of physical destruction not only indicated that an unbelievably large force had been released but also raised the question as to whether this force could be harnessed to the peaceful pursuits of mankind.

Today, more than a decade later, there is much evidence to show the usefulness of the atom in medicine, industrial applications and power generation. But as in the case of other technical developments, there is a disposition to accept the outcomes of scientific and technological developments without realizing that at one time there was serious doubt that they were even possible. In a sense, prior to every material accomplishment there is a stage at which the skeptics insist, "It can't be done!"

A good case at point is the Experimental Boiling Water Reactor which is now generating electric power for Argonne National Laboratory. During the dedication ceremonies on February 9, one of the engineer-scientists who participated in the early development of the boiling-water concept recalled some of the reasons why, in the pioneering days, some believed that a boiling-water reactor could never be satisfactorily designed to generate power. The skeptics stated that such a reactor was inherently unsafe and uncontrollable. And furthermore, what power plant operator would ever tolerate radioactive steam and feedwater in his plant? How could turbines, condensers, pumps, valves and piping be maintained without cumbersome shielding and expensive remote control equipment?

Yes, the skeptics had their day, but so did those who had faith in the soundness of the boiling-water concept. As described and illustrated on pages 53–58 of this issue, EBWR is the first of the demonstration projects of the U. S. Atomic Energy Commission's Experimental Power Reactor Program to go into operation. Now supplying some 5000 kw of electrical capacity to the Argonne National Laboratory, EBWR is an answer to those who said, "It couldn't be done," and a tribute to the scientists and engineers who had faith in a concept and the will and the courage enabling them to prove that it could be done.

Coal Markets In Florida?

Appalachian Coals, Inc., recently reported on a meeting sponsored by Senator Thruston B. Morton of Kentucky in Washington, D. C., to consider the development of a Florida market for coal. The major factor that makes such a market potentially feasible is that energy demand in Florida is doubling every five years (twice the national average). Coupled with this basic fuel energy requirement is the growth of phosphate production within Florida and the accompanying need for transportation devices to move phosphate out to its markets within the U.S.A. Coal and phosphate could conceivably use the same carriers.

Just how successful the above meeting will prove or how long the experts feel it will take before the potential market becomes an actual one is not known to us. The present energy demand (industrial and utility) amounts to the equivalent of 12 million tons per year and is expected to reach 24 million in 1962 and continue to increase at this same rate. Obviously such a huge market can yield distinct benefits to the coal industry. We think they can be long range as well as immediate.

The promise of profits is strong enough to justify a detailed market study aimed at solving the first problems of pricing, transportation, and conversion costs of customer plants and equipment. This certainly will be done. The future of the projected market seems vast enough to warrant a look at certain of the suggested solutions for one of coal's persistent headaches, transportation costs. This we think should also be done.

We understand present cost estimates for washing coal at the mine site, for example, run about 35 to 40 cents per ton. The benefits from such washing are reported to be a lowered sulfur content, a reduced boiler furnace maintenance and a higher fuel value per ton of coal or, in other words, less waste matter to haul and hence less transportation charges per unit of fuel energy.

At the moment the larger utility feels the boiler manufacturer should design his equipment to meet sulfur problems and combat furnace maintenance factors. Further, at a cost of 35 to 40 cents a ton for possibly partial relief power men believe the maintenance difficulties that unwashed coals present can be handled by conventional means at the utility level for less money. Hence it appears that transportation savings are the main point of sale for more preparation procedures at the mine. The coal industry should accept the challenge and see if it can either reduce preparation costs so all its benefits will apply or determine definitely if additional preparation can produce sufficient transportation savings to be worth while.

The problems of plant operation and of dependability presented by modern high-pressure and ultra-high-pressure steam power stations have led to the widespread adoption of automatic control systems. The following article investigates the mathematical basis of pressure and combustion control in steam generators in the light of the present state of the art. Account is also taken of reheating.

By DR. P. PROFOS

*Dynamics of Pressure and Combustion Control in Steam Generators**

IN ALL industrial countries which derive the greater part of their power from steam the percentage of the total power generated in high-pressure plants has increased rapidly in the last ten years and is still on the up-grade. Thus, although combined heat and power generation is still expanding, it is to be expected that ultra-high pressure plants will be used more and more in future for compensating large daily load fluctuations. In some cases they are even being called upon to help in the control of minute or second fluctuations, i.e., in frequency maintenance. This applies not only to public power supplies but in many cases to industrial power stations which are either completely independent or give up fixed amounts of their power to the grid.

As there is at the same time a trend towards bigger unit outputs and to stricter demands in the way of reliability and economy of operation, the development described above has clearly added to the importance of automatic control, and more particularly automatic pressure and combustion control. It is obviously desirable in these circumstances for the control properties of a boiler plant to be known even when it is still on paper, and this means that methods must be found of making the necessary calculations in advance.

The theoretical treatment of these control problems is not new. As early as 1926 Stein (13)[1] investigated combustion control by mathematical means and solved the problems encountered in a manner which was entirely adequate under the conditions then prevailing. Papers on the subject which have appeared since (3, 5, etc.) have added nothing that is really new to the work done by Stein, at least as far as the basic dynamics of control are concerned. In the meantime, however, steam techniques in general and steam generators in particular have developed rapidly. As a consequence of increased pressures and temperatures the evaporator has become an even smaller part of the total heating surface, while there has been a simultaneous increase in the internal pressure drop in the steam generator. This applies particularly to the once-through forced-circulation steam generator, which is gradually supplanting the orthodox natural-circulation boiler in the high-pressure field. As a result there has been a marked shift in the basic data on which the dynamics of boiler control depend, as will be clear from the following considerations.

The influence of the steam pressure on the energy content of the steam generator, which is very well expressed in the so-called storage capacity, is much lower in modern plants then in the older types of boiler (4, 6, 7, 8, 13). At the same time the load on the boiler has a greater effect on the energy content, so that the importance of these two factors is today completely changed. This is illustrated by the following figures for a few typical boiler designs:

Approximate ratio of the time of storage to the time constant of thermal inertia for

fire-tube boilers	1:1
drum-type natural-circulation boilers	1:6
once-through forced-circulation boilers	1:60

In view of these facts, it seems necessary to revise the established mathematical formulation of the dynamic behaviour of the steam generator, as the only feature so far taken into account has been the dependence of the energy content on the pressure. In addition, the theoretical basis must be extended to include reheating,

* Reprinted by permission from the Sulzer Technical Review, vol. 37, No 4, 1955. This article was first published by the Association of Former Students of the Swiss Institute of Technology on the occasion of the centenary of this Institute in 1955.

[1] The figures in parentheses refer to the bibliography at the end of the article

Fig. 1—These diagrams exemplify the basic principles of the two control methods—pressure and control—described above

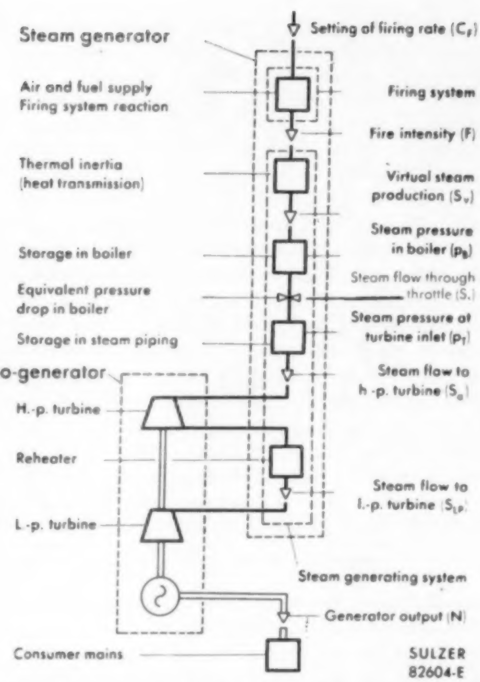


Fig. 2—Simplified presentation of the processes in the controlled system permits the choice of a substitute dynamic system for control purposes

which is being employed more and more frequently today.

The purpose of the following article is therefore to reformulate the basic dynamics of pressure and combustion control in steam generators and to bring them in line with the present-day technical facts.

Basic Problem

The purpose of pressure and combustion control in a steam generator is subsidiary to the main purpose served by the control system of the power station as a whole, viz. to adapt the power production to the demand. To this end the main characteristics of the working process, in particular the pressure and temperature of the live steam, must be kept within a fixed range, both in order to maintain a good plant efficiency and for reasons of safety and reliability. It is of course possible for the demand of the consumer and the actual output of the power station to be coordinated more or less closely in time. Thus if the station takes part in frequency control or is the only source of power of an independent consumer, the coordination will have to be rigid. The fundamental arrangement will then be that shown in Fig. 1(*a*), in which the prime mover takes the amount of steam required to meet the power demand, quite regardless of the effect on the working conditions of the boiler. If instead a station takes over the base load or is run to programme, the practical method of coordination would be that illustrated in the control system of Fig. 1(*b*). The generator output in this case does not affect the amount of steam flowing through the turbine; on the contrary, the output depends on the steam quantity produced by the boiler operating at constant pressure.

In both cases the pressure is essentially the factor which is being kept under control. The nature of the disturbance from the outside, however, and the control action are different. In the first case, which we shall term combustion control, the steam quantity is imposed on the boiler from outside, and the duty of the automatic control is to act upon the firing system and thus to modify the steam production in such a way that the pressure remains within the specified limits. In the second case, which we shall term admission pressure control or simply pressure control, the firing rate is the independent variable which directly determines the amount of steam produced. The supply of steam to the outside is then regulated by the pressure control system in such a way that the live-steam pressure is always maintained. Both of these cases are important in practice, and not infrequently they are combined in the same plant, where either alternative can be applied at will.

We shall now turn to the basic dynamics of combustion and pressure control.

Mathematical Formulation of the Dynamics of the Steam Generator

In setting up the equations for the dynamic behavior of the steam generator, we started out from measurements obtained in large modern boilers, and more particularly once-through forced-circulation boilers (1, 4, 6). From these we developed simplified presentations of the physical processes involved, which in reality are extremely complicated. It is these test results, with certain considerations of mathematical and experimental expediency, that form the basis of our method of dividing up the complex of problems by treating the processes taking place in the firing system and the actual steam-generator system separately.

Division of the problem. Before setting up the control equations, it will be worth while to consider briefly the processes with which we are concerned. Fig. 2 is a simplified diagram of the sequence of these processes and of the equipment in which they take place. Although this figure relates primarily to the general case of combustion control and reheating, it can be applied with suitable modifications to pressure control and to plants without reheating.

If a control signal for the adjustment of the firing rate is received, the following processes take place in the steam generator. The adjusting signal is first transmitted to the air and fuel metering equipment, if necessary after preliminary conversion into a more suitable form. As the dynamic behavior of the air and fuel regulating devices as a rule differs, the movements of the two usually have in addition to be attuned to each other so as to avoid any big fluctuations of the air excess during changes of load and to ensure optimum combustion conditions in steady operation. The changed amounts of air and fuel now enter the combustion chamber, where the desired intensity of the fire is normally attained with a certain time lag.

The changed intensity of the fire in its turn affects steam generation, once more with a time lag, as the new temperature gradient for the transmission of the changed amount of heat through the tube walls must first be established, while the tubular system and the steam content of the boiler also have to adapt themselves to the new load conditions. If the final pressure of the boiler were constant, a definite variation of steam production

as a function of time would now result. For the purposes of calculation, it is convenient to work with this "virtual steam production," which in fact approximates closely to the actual production with pressure control.

As a rule the pressure at the end of the boiler will actually change, and the storage capacity of the boiler will therefore come into play. This storage takes place mainly in the heated portion of the boiler and to a lesser extent in the pipes leading from the boiler to the points of consumption. When there is a change in pressure at the point of consumption, an immediate effect is produced in practice only by the steam quantity stored in the pipes in the close proximity of the consumer; the steam stored in the boiler makes itself felt only after a certain time lag on account of the internal pressure drop. Measurements have shown that generally speaking—and particularly in case of once-through forced-circulation boilers—the effect of this pressure drop, although in reality distributed over a large part of the steam-generator system, can be represented with sufficient accuracy by an equivalent pressure drop concentrated at the end of the boiler. This permits the calculations to be considerably simplified.

As mentioned above, the steam flow to the turbine must be regarded in the case of combustion control as being imposed on the steam generator from the outside. In pressure control it follows from the control action, which is decided by the adjustment of the intensity of the fire and the dynamic behavior of the pressure control system.

In plants without reheating we may assume for our present purposes that the electric output alters immediately with the quantity of steam flowing to the turbine, provided of course that the frequency is constant. When the frequency also varies, the energy of the rotating masses will affect the issue, and this includes the frequency-power characteristics of the consumer mains as well as the flywheel masses of the turbo-generator set.

In plants employing reheating the total output is produced in two or more turbine sections between which the reheater surface is interposed. In the pure condensing power station the steam throughput of these two turbine sections (or more with multiple reheating) will be the same in steady operation, provided that we disregard differences due to preheating with bleeder steam. If the reheater pressure is altered, however, the storage effect of the reheater produces differences in the steam flow as a function of time, and this results in a corresponding displacement of the output distribution over the turbine sections. This applies particularly to the case in which the reheater pressure is dependent on the load, which is examined in more detail below.

In the light of these general observations, we shall now attempt the mathematical formulation of the control behaviour, more particularly that of the steam generator, investigating the various dynamic elements separately. We assume for this purpose that the properties of the controlling means are known. The performance quantities used are to be considered as relative quantities, i.e., as deviations from a reference quantity. For steady operation, in particular, we assume the following[2]:

$$C_F = F = S_v = S_{RH}$$

This does not prevent us from regarding these quantities as dimensional in individual equations.

The influence of load is not specially represented in the equations; it can be regarded as being included in the constants, so that the derived equations also hold good at partial loads.

Dynamic behavior of the firing system. As already pointed out, it is convenient to keep the dynamic behavior of the firing system separate from the processes taking place in the steam generator. This procedure alone permits the influence of the firing system on the whole control behavior in the steam generator to be studied and thus gives a clear idea of what is involved in the choice between the various types of firing systems.

The term "dynamic behavior of the firing system" is

[2] See notation at end of article.

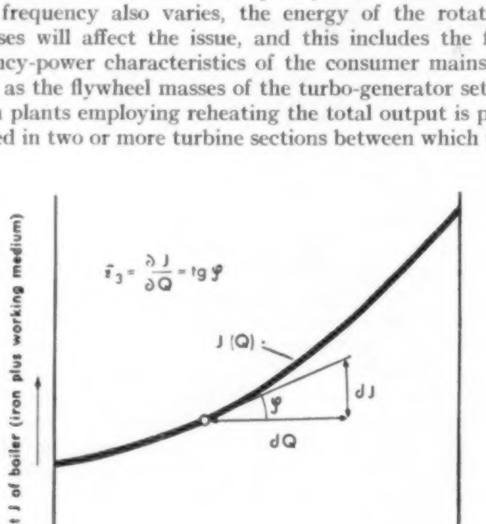


Fig. 3—The constant Z_3 of the thermal inertia of the steam-generator system is obtained as a differential coefficient from this diagram

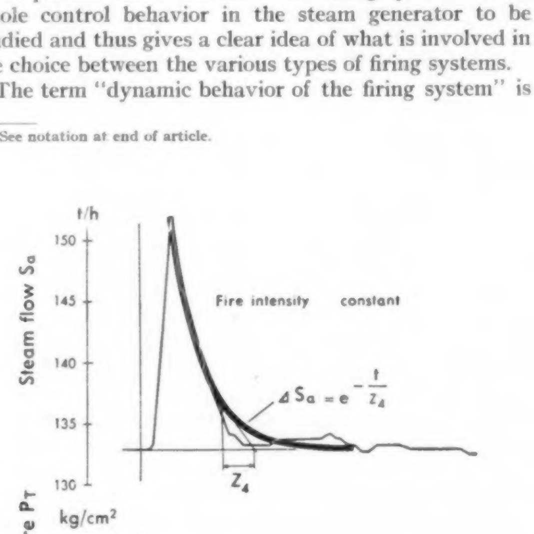
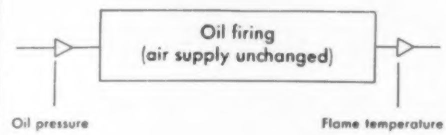
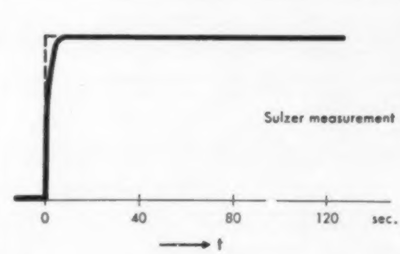
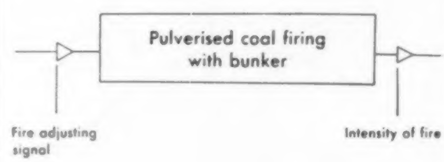
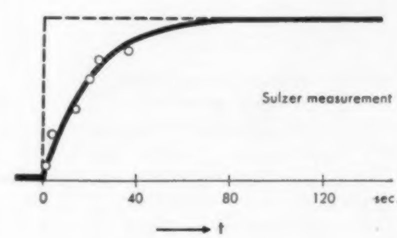
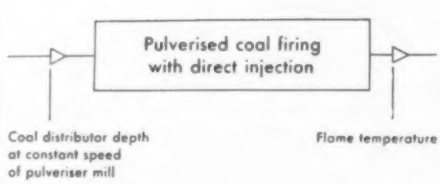
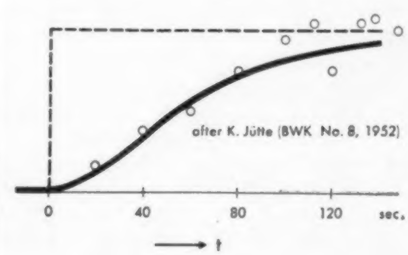
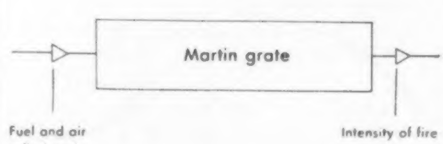
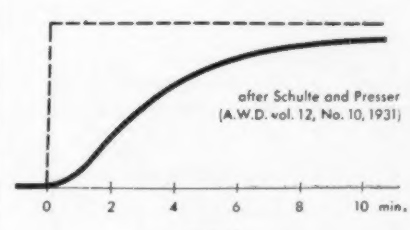


Fig. 4—Z_4 is obtained from the experimentally determined variation in the steam flow after a change in the final pressure in the boiler

here used to denote the dependence of the variation of the intensity F of the fire as a function of time on the control signal C_r transmitted to the air and fuel supply equipment. It naturally depends to a large extent on the type of firing system used and on the regulating means for the air supply. The test results given in Table I illustrate the big differences in the curves and time scales of the transient-response functions for a number of typical firing systems. In spite of the big discrepancies, however, it was found that time behavior can in general be characterized with sufficient accuracy by a finite distance velocity lag T (dead time) and a time constant Z (Table II, 1). Time behavior of this kind can admittedly not be reproduced in the compact form of a differential equation. However, the corresponding frequency-response characteristic can be mathematically formulated. Written in the complex form, this leads basically to the following:

$$F = \frac{e^{-T \cdot p}}{1 + Z \cdot p} \tag{1}$$

TABLE I—EXPERIMENTALLY DETERMINED TRANSIENT RESPONSES FOR FEW FIRING SYSTEMS

No.	Firing system	Transient-response function (test results)
1		
2		
3		
4		 SULZER 82611-E

The corresponding frequency-response curve is reproduced by way of example in Table II, 1.[3]

In the common case of *pulverized-coal firing with a bunker* the dead time T is often negligibly small and a formula with a single time constant is therefore sufficient, so that the time behavior can be expressed in compact mathematical form as follows:

$$C_F = F + Z_1F' \qquad (2)$$

The corresponding transient and frequency responses[4] are shown in Table II, 2.

In practice, moreover, there is often no genuine dead time in rapidly controllable pulverized-coal firing systems with direct injection, and the same applies under some conditions to grate-type stokers. The properties of the time behavior can then usually be formulated in an equation using two time constants:

$$C_F = F + (Z_1 + Z_2)\, F' + Z_1Z_2F'' \qquad (3)$$

This equation corresponds to transient and frequency responses as shown in Table II, 3.

The details of the processes taking place in the firing system and in the pulverizing mill during a change of load have been very little studied. The time constants T, Z, Z_1 and Z_2 must therefore be determined by measurements in existing plants.[5]

Dynamic behavior of the steam-generator system. In setting up the control equations for the steam generator as distinct from the firing system we shall first consider the processes which characterize the thermal inertia of the system. When the load changes, the energy content of the system corresponding to the new load must first be built up before the change in the firing rate can have its full effect on steam production. The processes in question are essentially "filling-up" processes, as the

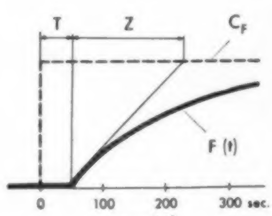
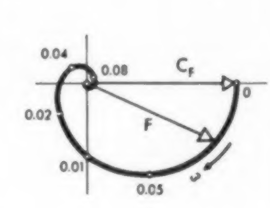
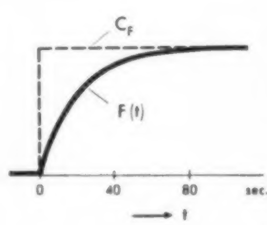
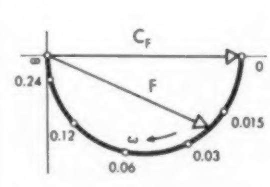
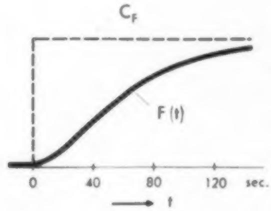
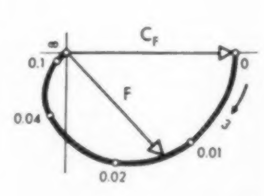
[3] This and all the other curves with frequency figures were calculated from measured transient responses.

[4] The corresponding formulae for the complex frequency response can be constituted directly from the differential equations and have therefore not been specially indicated here.

[5] The many test results published in this connection rarely permit the properties of the firing system to be directly inferred, independently of the steam-generator system, nor can these properties normally be deduced from the particulars given as to the other parts of the plant included in the investigations. Closer attention to control problems would be highly desirable in further tests of this nature.

TABLE II—METHODS OF REPRESENTATION FOR THE TIME BEHAVIOR OF FIRING SYSTEMS

The curves are numerically valid for the firing systems selected as examples.

No.	Firing system	Transient response	Frequency response
1	C_F → Example: Pulverised-coal firing with direct injection (slow regulation) → F $F(p) = \frac{e^{-Tp}}{1+Zp}$ (Frequency response)		
2	C_F → Example: Pulverised-coal firing with bunker → F $C_F = F + Z_1F'$		
3	C_F → Example: Pulverised-coal firing with direct injection (fast regulation) → F $C_F = F + (Z_1 + Z_2)F' + Z_1Z_2F''$		

SULZER 82612-E

delays due to the finite velocity of heat transfer play only a subordinate part. It is true that these heat transfer processes are a determinant factor in the change of the heat content of the brickwork, but this component of the energy is of minor importance in modern boilers. Furthermore, the heat content of the brickwork changes so slowly that it is of no significance in relation to the comparatively rapid load fluctuations which are under consideration here.

The dependence of the virtual steam production S_v on the intensity F of the fire can therefore be characterized by the following differential equation:

$$F = S_v + Z_3 S_v' \qquad (4)$$

where the time constant Z_3 is the time which would be necessary, after an increase of output (e.g., by 1 per cent of full load), to bring the energy content of the boiler up to the value of the new steady state by a corresponding increase in the heat supply, it being assumed that the final boiler pressure p_T remains unchanged. If, then, Q is the amount of heat transferred per hour and J is the load-dependent energy content of the boiler, the constant $Z_3 = \frac{\partial J}{\partial Q}$ for a given load level β is found to be the tangent of the curve $J = f(Q)$ at the load point concerned (Fig. 3). The curve $J = f(Q)$ can in practice be calculated by plotting the heat content of the tube system per unit tube length $\frac{dJ}{dl}$ (iron plus working medium) over the tube length l for various load levels and then obtaining J by integration over l.

The effect of storage and of the equivalent pressure drop on the relationships between the virtual steam production S_v, the steam flow S_a to the turbine and the pressures p_B in the boiler and p_T at the turbine inlet can be formulated in the following equations:

(a) $S_v + S_B = S_z$	Working-medium balance of the boiler
(b) $S_B = K_4 p_B'$	Storage equation of the boiler
(c) $S_z = K_5 (p_B - p_T)$	Equivalent pressure drop
(d) $S_a = S_z + S_P$	Working-medium balance of piping
(e) $S_P = -K_6 p_T'$	Storage equation of piping

In equation c for the equivalent pressure drop there will not in reality be any linear relationship. However, as the only important point for the rest of the calculation is the interdependence of the changes in the various quantities, or in other words only the derived form of equation c, viz.

$$(c') \qquad S_z' = K_5 (p_B' - p_T')$$

we can always take account of the actual exponential law, for small changes, by suitable choice of the coefficient K_5. Consequently the simple form of equation c is quite permissible.

Equations a to e apply on the usual assumptions. In particular, the pressure changes must be relatively small and temperatures practically constant.

By eliminating the quantities which are not of immediate interest to us, viz. p_K, S_z, S_B and S_P, we obtain from the simultaneous system a to e the differential equation (5), which relates the pressure at the turbine inlet to the virtual and actual steam output:

$$S_v - S_a - Z_4 S_a' = (K_4 + K_6)\, p_T' + K_6 Z_4 p_T'' \qquad (5)$$

The constants K_4, K_6 and $Z_4 = \frac{K_4}{K_5}$ are defined by equations a to e and have the following physical significance: The quantity K_4 corresponds to the relative storage capacity of the steam generator and is the storage steam quantity obtained when the pressure p_B drops by one unit of pressure. K_6 is the same storage value for the pipe between the boiler and the turbine. It can be calculated approximately from the relationship $K_6 \approx \frac{G_P}{p_T}$, where G_P is the working-medium content of the piping. The quantity Z_4, which is a time dimension, is obtained by measurement from the variations of the steam output S_a as a function of time after a change in the pressure level p_T. If p_T is constant again after this pressure variation, i.e., $p_T' = p_T'' = 0$, it follows from equation (5) for the difference ΔS_a between the steam output S_a and the constant virtual steam production S_v that

$$\Delta S_a = e^{-t/Z_4} \qquad (5.1)$$

Z_4 can therefore be obtained as a subtangent from the steam quantity curve tending towards the steady-state value (Fig. 4).

By combining equations (4) and (5) we obtain the differential equation of the steam-generator system (6), which gives us the desired relationship between the fire intensity F, the steam output S_a and the pressure p_T at the turbine inlet.

$$F - S_a - (Z_3 + Z_4)\, S_a' - Z_3 Z_4 S_a'' = (K_4 + K_6)\, p_T' + [(K_4 + K_6)\, Z_3 + K_6 Z_4]\, p_T'' + K_6 Z_3 Z_4\, p_T''' \qquad (6)$$

This equation holds good both for combustion control and for pressure control. In the case of combustion control the chief interest attaches to the effect of a changing firing rate on the pressure variations at constant steam output, while the pressure variations at the turbine inlet as a function of the steam output at constant firing rate are of interest in both cases. With pressure control it is furthermore important to know how the steam output and thus the turbine output vary when the pressure is constant but the firing rate changes. These relationships can be obtained from equation (6) as described below.

If it is desired to investigate separately the effect of a change in the steam output on the pressure, we set out for instance from $F = F_0$ = constant and $\Delta S_a = S_a - F_0$ and thus obtain from equation (6).

From this equation we can determine transient and frequency responses, the basic form of which is shown in Table III, 1.

The behavior function for the effect of the fire on the pressure at constant steam output is also obtained as a special case from equation (6).

$$-\Delta S_a - (Z_3 + Z_4)\, \Delta S_a' - Z_3 Z_4 \Delta S_a'' = (K_4 + K_6)\, p_T' + [(K_4 + K_6)\, Z_3 + K_6 Z_4]\, p_T'' + K_6 Z_3 Z_4\, p_T''' \qquad (6.1)$$

with $S_a = S_{a0}$ = constant, the time derivatives of S_a disappear, and with $\Delta F = F - S_{a0}$ we obtain:

$$\Delta F = (K_4 + K_6) p_T' + [(K_4 + K_6)\, Z_3 + K_6 Z_4]\, p_T'' + K_6 Z_3 Z_4\, p_T''' \qquad (6.2)$$

The forms of representation of the dynamic behavior corresponding to this differential equation, viz. transient and frequency responses, will be found in Table III, 2.

Finally, the variations in the steam output with changing firing rate and constant pressure p_T can also be obtained from equation (6). In this case the time derivatives of p_T disappear and we are left with the equation

$$F = S_a + (Z_3 + Z_4)\, S_a' + Z_3\, Z_4\, S_a'' \qquad (6.3)$$

from which again the transient and frequency responses can be obtained. Typical curves of this kind are shown in Table III, 3.

Dynamic behavior of a steam turbine with a reheater. In plants without reheating the time lags due to the clearance spaces in the interior of the steam turbine play only a minor part in the regulating processes under consideration here. When the reheater pressure is variable, however, and particularly when it is dependent on load, this feature can no longer be neglected and may under some circumstances result in serious modification of the control conditions. Owing to the storage action of the fairly large steam space in the reheater and piping, the output of the low-pressure turbine lags noticeably behind that of the high-pressure section when changes occur. After an increase of load, for instance, the reheater pressure must first be raised, and after a decrease of load a corresponding amount of steam must be passed to the low-pressure turbine (Figs. 2 and 5) before the steady-state output distribution over the two turbines can be restored. With automatic combustion control, and especially when the boiler participates in frequency stabilization, the control conditions for the steam generator are therefore considerably more difficult, under otherwise similar conditions, than in plants without reheaters. This point will be dealt with in more detail below.

The storage action of the reheater is of course present

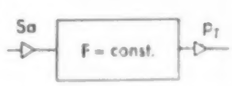
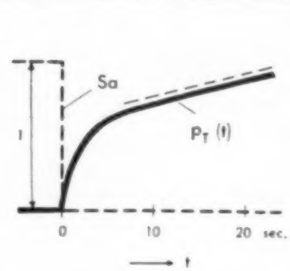
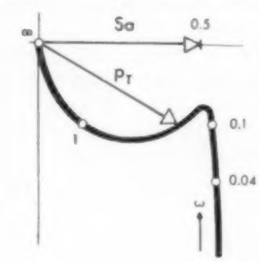
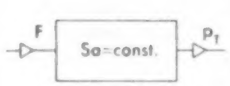
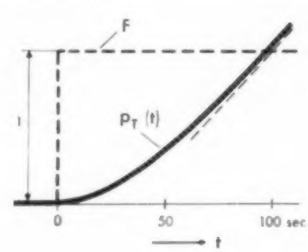
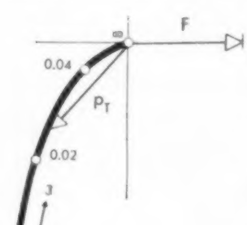
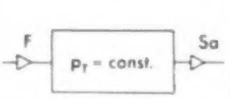
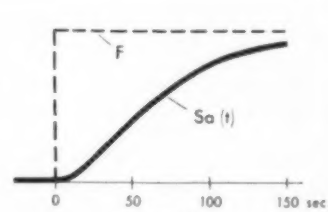
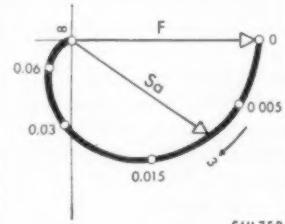
TABLE III—TIME BEHAVIOR OF THE STEAM GENERATING SYSTEM UNDER VARIOUS CONDITIONS

The curves are numerically valid for Sulzer Monotube steam generators.

Steam generating system

General differential equation

$$F - S_a - (Z_3 + Z_4)\, S_a' - Z_3 Z_4\, S_a'' = (K_4 + K_6)\, p_T' + \left[(K_4 + K_6)\, Z_3 + K_6 Z_4\right] p_T'' + K_6 Z_3 Z_4\, p_T'''$$

No.	Dynamic system	Transient response	Frequency response
1			
2			
3			

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with pressure control also, but owing to the different control link-up it has practically no effect on the steam generator (Figs. 6(*a*) and 6(*b*)).

The mathematical handling of these processes is simplified by the fact that the enthalpy differences of the two parts of the turbine change very little even when the load varies and may therefore be regarded as being practically constant. On the assumptions set forth above, the desired relationship between the total output N of the turbo set and the steam supply S_a can then be obtained from the following equations:

(*a*) $N_{HP} + N_{LP} = N$ Balance of turbine outputs
(*b*) $N_{HP} = n \cdot h \cdot S_a$ Mean output distribution over
(*c*) $N_{LP} = (1 - n) \cdot h \cdot S_{LP}$ the two parts of the turbine
(*d*) $S_a = S_{LP} + Z_{RH} \cdot S'_{LP}$ Storage equation of the reheater

By eliminating the quantities N_{HP}, N_{LP} and S_{LP} we obtain the desired differential equation:

$$h \cdot S_a + n \cdot h \cdot Z_{RH} \cdot S_a' = N + Z_{RH} \cdot N' \qquad (7)$$

The time constant Z_{RH} which characterizes the storage behavior of the reheater can be calculated with sufficient accuracy for practical purposes from $Z_{RH} \approx \frac{G_{RH}}{S_a}$, where G_{RH} is the working-medium content of the reheater including the piping.

In reality the assumptions made in arriving at this differential equation (7) are not completely fulfilled; but the resulting errors are small and in part cancel each other out over a full load cycle, as is shown by a comparison of the results obtained on these simplified assumptions and those arrived at by accurate calculation without linearization, i.e., calculus with finite differences (Fig. 7).

To illustrate the effect of the reheater on controllability, we can again investigate the time behavior for the cases which are of greatest practical importance.

In the case of pressure control the live-steam supply S_a is, for the group comprising the turbogenerator and the reheater, the independent variable. The output N of the generator to the mains is then the resulting quantity. We can now calculate the transient and frequency

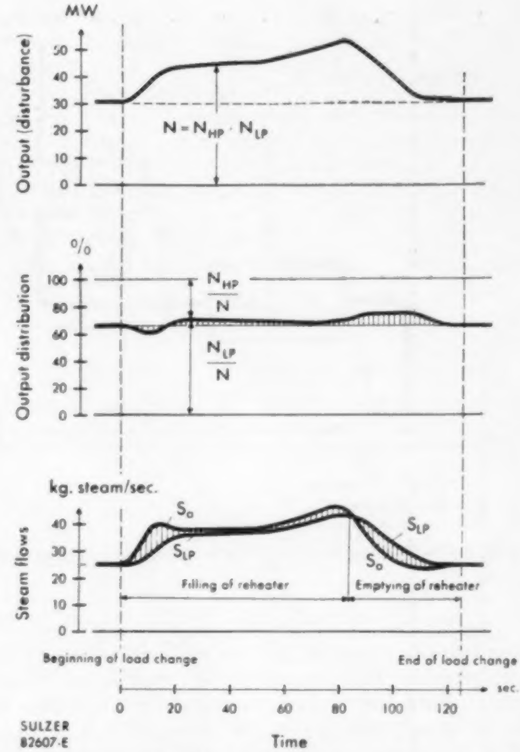


Fig. 5—Storage effect of a reheater can influence the distribution of output over the high-pressure and low-pressure parts of the turbine when the load changes. (Example: 60-MW industrial block type power station)

responses for this case by the known methods from differential equation (7). Curves of this type are shown in Table IV, 1. The run of the transient response in particular illustrates very well the retarding action of the reheater on the power output, especially if compared with the corresponding function plotted as a broken line (without reheating).

In the case of combustion control the generator output

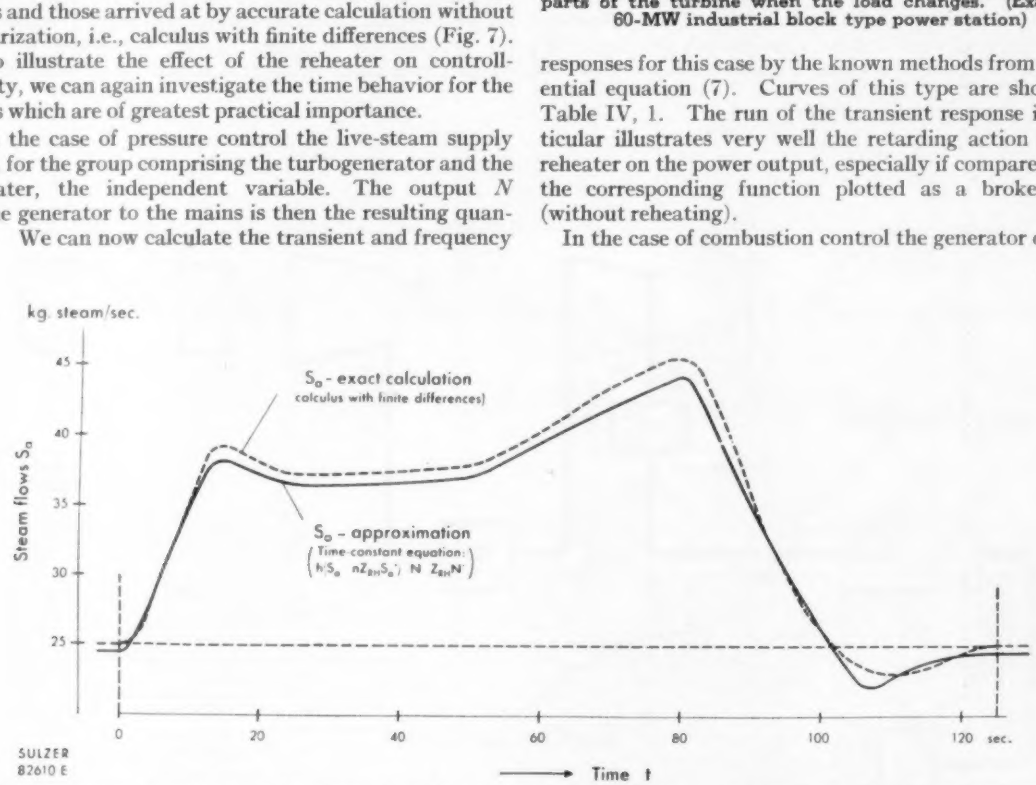


Fig. 7—Live-steam quantity as a function of sudden and considerable changes of load for a 60-MW turbo set with reheater, as determined by exact calculation (broken line) and as obtained with the approximative equation (full line)

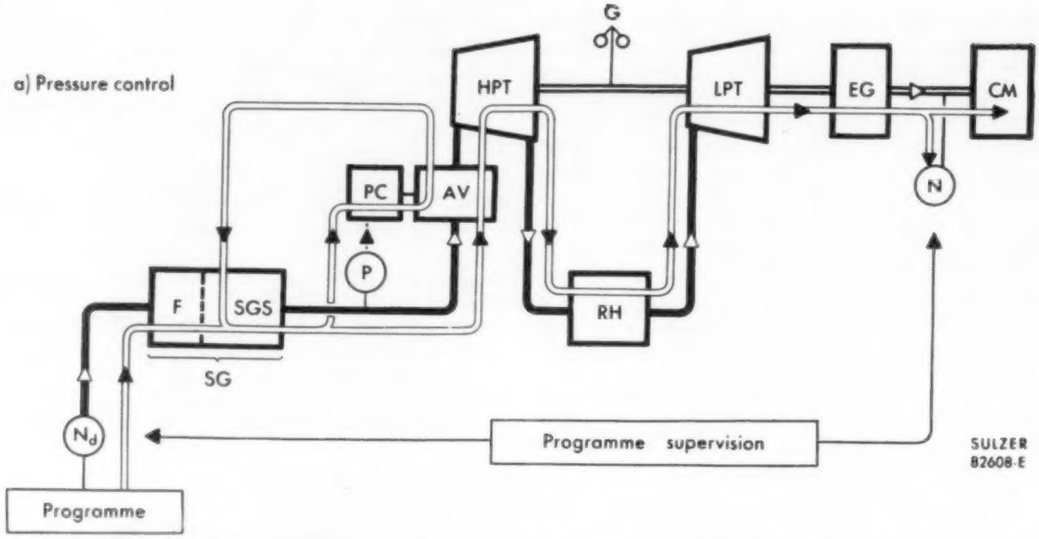


Fig. 6 (a)—**Disturbance and control action in a steam power station with reheater** (a) **automatic pressure control**

is the primary variable and its changes, produced by fluctuations of the demand in the mains, are transmitted to the live-steam consumption of the turbine. In differential equation (7) we now work with N as input and S_o as output variable; the resulting transient and frequency responses will be found in Table IV, 2. Here again the transient response shows especially clearly that, as a result of the storage action of the reheater, the variation in the live-steam flow is much less favorable with a rapid change of output than it is in the absence of reheating, when the total output and the steam flow take practically the same course.

The effect of such a load change on the admission pressure p_T can be established by taking account of the behavior of the steam generating system as set forth in equation (6) with constant firing rate. Starting from the generator output and working towards the pressure p_T, we then obtain transient and frequency responses of the type shown in Table IV, 3. Compared with an instance of a plant without reheating (in practice curves

Fig. 6 (b)—**Disturbance and control action in a steam power station with reheater** (b) **automatic combustion control**

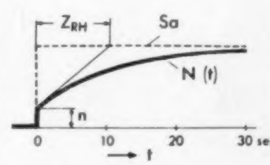
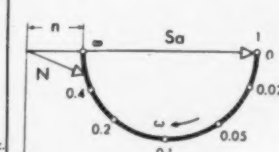
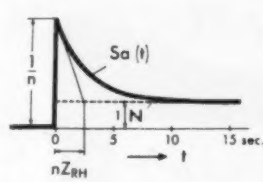
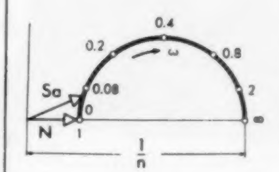
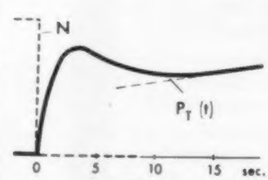
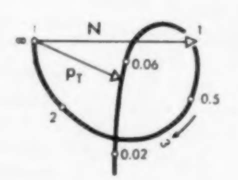
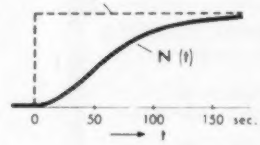
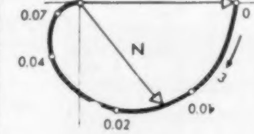
as shown in Table III, 1), these curves again show that the control properties are rendered basically less favorable, and at the same time less amenable to empirical treatment, as a result of the storage effect of the reheater.

On the basis of the above we can now examine the dynamic behavior of the complex of steam generating system, reheater and turbo-generator for the case of pressure control, where the variation of the output as a function of the intensity of the fire is the feature which interests us most. Typical curves are reproduced in Table IV, 4. Comparison with the corresponding curves without reheating (Table III, 3) shows—even in a concrete numerical example—that with pressure control reheater storage is of no practical significance by comparison with the other time-lag effects involved.

Where multiple reheating is adopted, this storage

TABLE IV—TIME BEHAVIOR OF DYNAMIC SYSTEMS

The behavior of the turbo-generator/reheater system and of the steam generator/turbo-generator/reheater system are shown. The curves are numerically valid for Sulzer Monotube steam generators.

No.	Dynamic system	Transient response	Frequency response
1	S_a → Turbo-generator Reheater → N $h(S_a + nZ_{RH}S_a') = N + Z_{RH}N'$		
2	N → Turbo-generator Reheater → S_a $N + Z_{RH}N' = (S_a + nZ_{RH}S_a')\,h$		
3	N → Steam generating system Turbo-generator with reheater → P_T F = constant $\left[N + (Z_3 + Z_4 + Z_{RH})N' + (Z_3Z_4 + Z_3Z_{RH} + Z_4Z_{RH})N'' + Z_3Z_4Z_{RH}N'''\right]\frac{1}{h} = -(K_4 + K_6)p_T' - \left[(K_4 + K_6)(Z_3 + nZ_{RH}) + K_6Z_4\right]p_T'' - \left[K_6(Z_3Z_4 + nZ_3Z_{RH} + nZ_4Z_{RH}) + nK_4Z_3Z_{RH}\right]p_T''' - nK_6Z_3Z_4Z_{RH}p_T''''$		
4	F → Steam generating system Turbo-generator with reheater → N p_T = constant (admission pressure control) $F + nZ_{RH}F' = \left[N + Z_3 + Z_4 + Z_{RH}N' + Z_3Z_4 + Z_3Z_{RH} + Z_4Z_{RH}N'' + Z_3Z_4Z_{RH}N'''\right]\frac{1}{h}$		

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effect of course presents itself several times and thus makes itself much more strongly felt in the above ways, especially in the case of combustion control. Unfortunately, in this more complicated case the situation is generally less favorable for the adoption of a simplified procedure such as that used for single reheating. Nevertheless, an approximative method is almost unavoidable in view of the enormous amount of computation otherwise involved.

Conclusion

The equations arrived at above, together with the known or given properties of the control equipment, provide us with a basis on which we can carry out all dynamic investigations lying within the range of validity of the fundamental relationships. It is true that this leads to sets of equations of high order, especially in the case of combustion control, and the use of analogue computing devices is therefore an obvious expedient, at least when repeated investigations have to be made. A device of this kind, constructed of hydraulic integration elements, is employed by the author's company.

Notation

C_F	= Control signal for adjustment of firing system
F	= Intensity of fire (firing rate)
S_v	= Virtual steam production (at constant pressure)
S_a	= Actual steam flow to turbine
S_B	= Storage steam quantity of boiler (per unit time)
S_P	= Storage steam quantity of piping (per unit time)
S_x	= Steam flow through the fictitious throttle, the latter representing the pressure drop in boiler
S_{LP}	= Steam flow to low-pressure turbine
S_{RH}	= Steam flow to reheater
G_P	= Working-medium content of piping
G_{RH}	= Working-medium content of reheater including piping
p_B	= Boiler pressure
p_T	= Pressure at turbine inlet
Z, T	= Time constants
K_4, K_6	= Storage constants
N	= Total turbine output
N_{HP}	= Output of high-pressure part of turbine
N_{LP}	= Output of low-pressure part of turbine
$n = \frac{h_{HP}}{h}$	= Proportion of total output due to high-pressure part of turbine (in steady operation)
h	= Total effective enthalpy difference
h_{HP}	= Effective enthalpy difference in the high-pressure turbine

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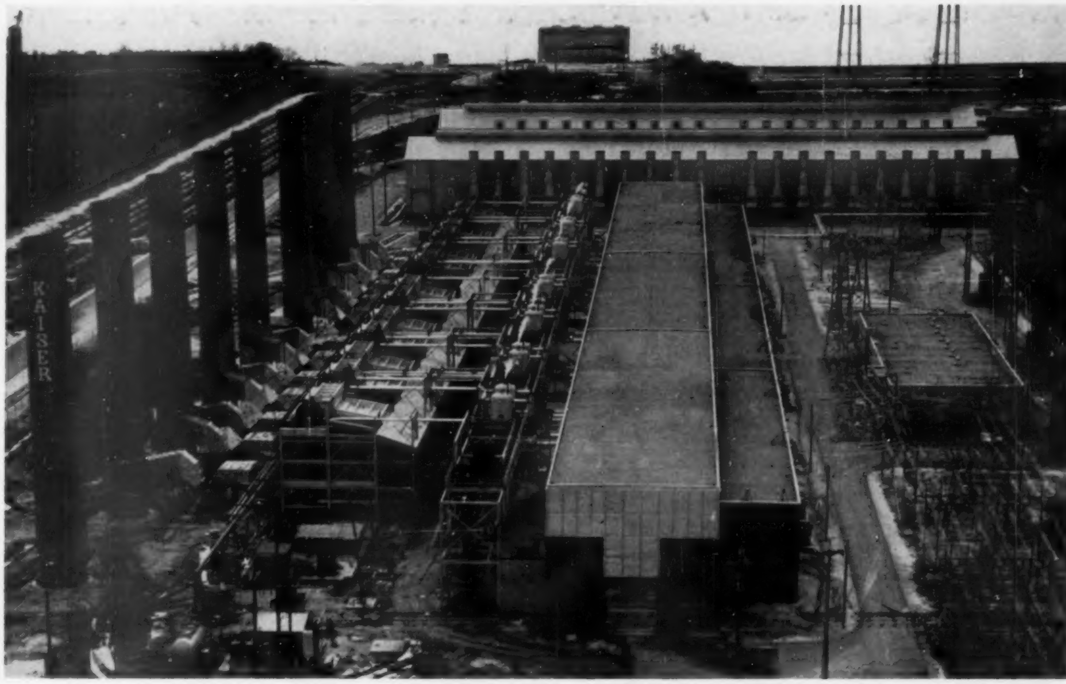

Fig. 1.—Immensity of the power facilities to supply steam and electrical needs of an aluminum producer is apparent in above view of Chalmette plant, Kaiser Aluminum & Chemical Corp. shown in night view on cover

Industrial Power Plant Developments*

By E. R. LEE, JR.
Kaiser Engineers

E. F. BOOBYER
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Industrial power differs from utility type power chiefly on its more complex use of energy at any one site. Here is a first-hand report by a leading aluminum producer making specific comparisons between an older and newer plant as well as gas engines against steam turbines.

THERE are many different and often unusual features imposed upon performance requirements of the industrial power plant which require different approaches to their design and operation from the conventional utility power plant. To obtain a better concept of some of these features and of the progress made in the industrial power field, we suggest tracing the developments of one of the outstanding industrial power users—the aluminum producer. Within the Kaiser Aluminum and Chemical Corporation there are three typical aluminum production plants: the aluminum reduction plant at Chalmette, the alumina production plant at Baton Rouge, and the new alumina plant now being built at Gramercy. All of these are in the State of Louisiana.

The location of these plants in Louisiana is significant because ocean-going vessels carrying bauxite from mines in Jamaica and Central American can use the lower Mississippi River to reach Baton Rouge and Gramercy in a single stage of transportation. Additional significant attractions to industry in this area are the relatively low cost of natural gas fuel, the abundant water supply, and the access to river barge and rail transport from other sections of the country. Generally, the freight rates and fuel costs tend to enforce such a location for this type of chemical plant in order for the plant to remain competitive in the total aspects of the aluminum industry.

Factors Affecting Design

The type of available fuel greatly influences the design of reduction power plant facilities. When natural gas is the main fuel, the choice of prime mover lies between gas engines, steam turbines and gas turbine-steam turbine combinations.

Electric power service to electrolytic reduction plants such as Chalmette is predicated upon the same philos-

* Presented before the Fall Conference, San Francisco Section, Power Division, ASME, San Francisco, Cal., Oct. 12, 1956.

Fig. 2—Power requirements at Chalmette dictated immediate solutions so company selected 80 radial gas engines for first 100,000 kw demand.

Fig. 3—Within two years of the first power block supplied by Fig. 2, another 375,000 kw was being supplied by 16 turbine generators.

ophy as utility power plants. Power is a major component of the electrolytic reduction of aluminum oxide to the metal form. Again, such economic factors as freight and power costs determine the location of the reduction plant. Further, the economics of industrial power plant design is associated closely with the economics of the overall industrial plant which the power plant is to serve. The intended pay-out period for an industrial power plant usually is considerably less than that of a typical utility.

The aluminum industry uses fuel energy in all three major divisions of the enterprise: the chemical production of aluminum oxide from bauxite, the electrochemical or reduction process for production of metallic aluminum from its oxide, and the production of finished products from the metal. The first two divisions of production require rather complex power and utility facilities to support the chemical processes.

Fundamental differences between the reduction process and the chemical process, as used at Baton Rouge and Gramercy, influence the design of reduction plant power facilities in that:

(1) Reduction plants use a continuous process and there are no occasions for a large scale curtailment of production activity in order to allow for maintenance and inspection.

(2) The majority of power is used in the dc form.

(3) Little or no process steam is required.

(4) The power plant may be physically removed from the reduction plant.

Power plants for both types of production processes are subject to the same economic pay-out period as are prescribed for the balance of the production facilities. Consequently, they must be of a design and location to require minimized capital expenditures and be supplied with a cheap form of fuel. Industry has the ability to locate in low cost fuel areas, if all other aspects of the plant operation are acceptable.

Chalmette—Power in a Hurry

The Chalmette plant, the nation's largest aluminum reduction plant, has power facilities with a present operating capability of about 485 mw (Fig. 1). Prime movers are steam turbines and gas engines, with the engines supplying about 25 per cent of the total power consumed. Chalmette created power problems that had to be solved immediately instead of by long-range planning. Kaiser Engineers, engineer-contractor for Kaiser Aluminum and Chemical Corporation, after commencing design in February, 1951, was faced with the problem of supplying 50,000 kw of dc as one block of power by November, 1951, and a second block of power of 50,000 kw of dc by January, 1952. This need for electric power was met first by the installation of 80 Nordberg vertical radial gas engine generating units (Fig. 2) which provided 103,000 kw of dc power for the first two potlines. In order to supply the future demand for dc and ac power required to produce up to 200,000 tons of aluminum per year by the end of 1953, the steam turbine generator plant (Fig. 3) of 375,000 kw ac rated installed capacity was built in addition to the gas engine generator plant.

The Chalmette electrolytic reduction facilities presently comprise eight potlines and a ninth is being installed. Two are presently fed direct from the dc generators in the gas engine plant while the remaining six potlines and the future ninth potline are supplied through the rectifier station from the ac steam generator plant.

Power from this steam plant at 13.8 kv ac is delivered to the mercury arc rectifier station. From there it is delivered to individual 13.8 kv, 720 v rectifier transformers which supply the anodes of the bank of rectifiers serving the potlines. Approximately nine kw of electric power are required to produce a pound of aluminum. The dc demand of each individual potline is in the order of 65,000 amps at 720 v.

Of these major power components the eighty Nordberg vertical radial type 400 rpm gas engines are directly connected to dc generators, each with a present capability of 1325 kw. These are unit elements, complete with all auxiliaries, and individual oil and jacket water cooling systems.

The steam electric plant consists of fourteen General Electric 3600 rpm steam turbine generators with 850 psig, 900 F throttle conditions, and $2^1/_2$-in. Hg. exhaust conditions, hydrogen cooled with direct connected exciters. Each unit has a present capability of 26,000 kw. Also two General Electric 3600 rpm steam turbine generators, 850 psig, 900 F throttle conditions, and $2^1/_2$-in. Hg. exhaust conditions, air-cooled, with direct connected exciters; each unit having a capability of 12,500 kw.

Steam is supplied by fifteen Foster-Wheeler boilers,

each rated 225 M pounds per hour at 850 psig, 905 F, gas fired only, with heat release of 35,000 Btu's per cu ft per hr, and equipped with F.D. and I.D. fans and regenerative air preheaters.

Cost Comparisons

The operating economics and capital costs of the two sources of power can be compared only in terms of dc power. Based on Chalmette experience, the technological advancement of the gas engine industry, and new techniques developed in the use of steam driven ac power equipment, both types of prime movers still are competitive for reduction plants up to about 100 M tons per year capacity. Advancements in the design of reduction process facilities coupled with the increasing size of reduction plant operations at one site indicate that large steam turbine generator-rectifier combinations probably will be the preferred type of power facility for future reduction plants located in natural gas fuel areas.

Chalmette maintenance costs, including supervisors, of the gas engine dc generator plants is about 2.75 times that of steam turbine-ac generator-rectifier station combinations. The costs of operating labor and supervision is about the same for both types of power plants.

The average annual net heat rate of the gas engine plant is 12,400 Btu/kwh (HHV) delivered to potlines, as compared with 13,200 Btu/kwh for the steam turbine plant delivered to rectifier station. However, the total operating economy of the steam turbine-generator-rectifier station combination is better than the gas engine dc system by about 10 per cent. Very little difference in unit final construction costs of the two systems is apparent.

Gas Engine Improvements

Developments in the gas engine industry since 1951–1952 has made the net heat rate of 9000 Btu/kwh (HHV) appear feasible for future installations using natural gas fuel. Significant progress in the art of supercharging, subcooling and control of combustion has increased the bhp capability of existing engine frames while simultaneously improving thermal performance. Thus, increased construction costs can be offset significantly by decreasing operating costs.

A 20,000 operating hour period between major gas engine overhauls is becoming an accepted fact in both utility and heavy industries. Chalmette records support this trend. The lowering of maintenance costs of large gas engine-generator plants can be anticipated with longer service hour runs per unit.

Generally, gas engine dc generator units are increasing in practical size, improving in performance, and decreasing in unit capital costs. For large dc power services they continue to remain competitive.

The Case For Steam

The choice of turbine-generator units capable of 26,000 kw at Chalmette was necessitated to some extent by the allowable delivery time. Units of the 40,000 kw size would have been more desirable economically according to the 1951 design philosophy as applied to a power plant not normally operating in parallel with a public utility power system. In 1951 it was considered necessary, both mechanically and electrically, to incorporate a stand-by boiler-turbine generator unit of 26,000 kw capability into the power plant. This was to allow for maintenance and inspection of the other fifteen power units without inflicting a power curtailment on the electrolytic process. Of necessity the power plant was designed around a "mass system" rather than a "unit system," where the boiler steam and feed water headers were single continuous systems (Figs. 4, 5) and a single continuous 13.8 kv synchronizing bus allowed for electrical interchange.

When a number of relatively small power units are employed, as at Chalmette, the cost of a stand-by power unit justified its ability to eliminate power interruptions which would result in loss of aluminum production during forced and scheduled outages of major power equipment.

As primary markets for aluminum metal have become established in particular geographical areas, and as freight and fuel costs have increased, there has been a change in design philosophy relative to large power facilities supporting electrolytic processes. Whatever

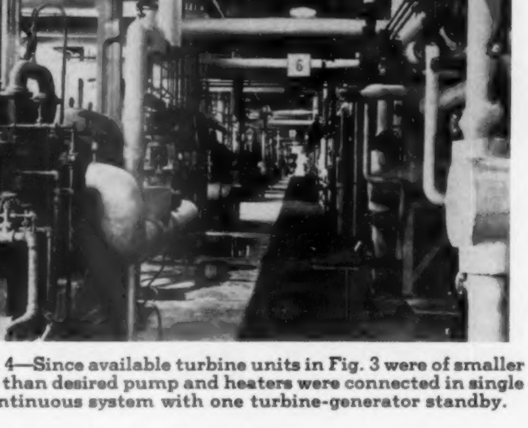


Fig. 4—Since available turbine units in Fig. 3 were of smaller size than desired pump and heaters were connected in single continuous system with one turbine-generator standby.

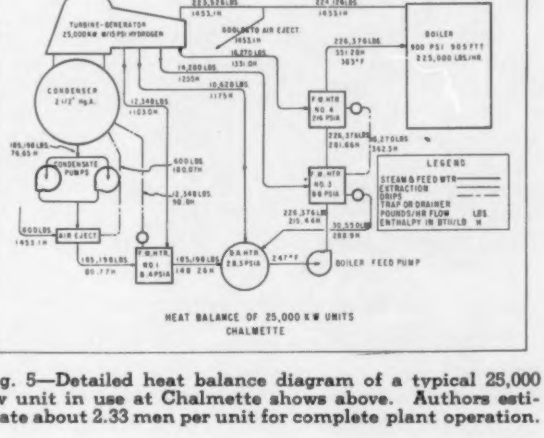


Fig. 5—Detailed heat balance diagram of a typical 25,000 kw unit in use at Chalmette shows above. Authors estimate about 2.33 men per unit for complete plant operation.

the fuel, its present day cost requires the investigation of the use of large, high pressure steam generating units for large electrolytic installations, although such power plants would not normally be affiliated with a utility power system. Obviously, the application of a small number of large generating units, totaling about 500 mw capacity and without a tie to a fairly large power system, would make the design provision of a stand-by power unit unrealistic. The capital cost of such an industrial power plant would be increased greatly over a conventional unity power plant to the point where its other competitive features would be offset.

Ideal Plant Design

An ideal steam power plant design philosophy as applied to an electrolytic process demanding 500 mw or more would incorporate these points:

(1) A low cost fuel source immediately at hand, either under long term supply contract or owned by the operating industry.

(2) The use of reheat steam turbine generator units of about 125 mw capability.

(3) The use of reheat boilers operating at about 1800 psig/1,000 F /1,000 F and each serving only one turbine-generator.

(4) No stand-by power facilities except for a small emergency power unit for initial starting or restarting of the plant.

(5) A system of process plant operation tied closely to the scheduled availability of power, so the best economic balance in total operating costs can be obtained for the process plant-power plant complex.

(6) The use of proved major power equipment and accessories so that maximum equipment availability is obtained.

(7) The use of a common electrical bus system and matching transmission system so that maximum flexibility of power flow is possible to the electrolytic process.

(8) The location of water source, process and power plants immediately adjacent to each other, so that power transmission costs will minimize the total metal production costs.

Such a philosophy is not an impractical one. In fact, we are at this time extending the reduction process plant at Chalmette so that the entire varying power output of the steam power plant can be utilized. We are consequently abandoning the concept of incorporating a stand-by power unit.

Chalmette has few departures from relatively standard utility power plant practices applicable to the use of 850 psig/900 F units. No "unit system" philosophy is applied, the mechanical and electrical design being able to accommodate a "mass system" or a series of "mass systems." Such a system allows maximum flexibility in operation and can be considered as the ultimate in operational requirements. However, we would probably now consider "unit systems" mechanically and "mass systems" electrically.

Chalmette's Operating Experience

At Chalmette the large number of identical generating units and their major auxiliaries, operating under very similar conditions by a single operating and maintenance crew, has allowed the collection of extensive performance and availability data. The continuous high load factor has inflicted strenuous operating conditions on all equipment since 1952.

It appears that 20,000 operating hours between major inspection overhauls for major equipment is readily acceptable and possibly should be extended to about 35,000 hours, with the possible exception of the "express" type boilers. Insurance company and State policies inflict continuous operating period of not more than 12 months on the boiler units at Chalmette.

For the most part the degree of availability can be predicted with fair certainty for major equipment, so long as a well planned maintenance program is enforced. However, if "preventative maintenance" is too extensive, it can lead to "destructive maintenance."

Because of the large number of steam power units at Chalmette no attempt was made to centralize the mechanical controls at the same location as the central electrical controls. Rather, very flexible and extensive communications were installed between all operating points with local control and instrumentation panels for boilers, turbines, boiler feed pumps. This has proved a practical arrangement. It has not increased the operating manpower above what would be required in a wholly centrally controlled system for a plot employing 16 units and controlling all mechanical and electrical functions. The number of operating units in any one plant dictates the number of operators and maintenance men to a greater extent than does the size of units. Considering the total operating and technical supervision and staffs at Chalmette under the conditions of having to operate all mechanical and electrical features, 2.33 men are required per generating unit. This number would not materially change if 125 mw units were substituted for the existing smaller units.

Our present viewpoint is that good and proven communications, with annunciation only in very general terms, is sufficient to allow enlightened operational practices. When a total central control of both mechanical and electrical features can be considered, local control panels with duplicate instrumentation need not be provided.

For the production of aluminum oxide KA&CC operates a plant in Baton Rouge to support electrochemical reduction plants at Chalmette, Louisiana and Spokane and Tacoma, Washington. A second plant is now being built at Gramercy, Louisiana, to supply material to the expanding electrochemical plant at Chalmette and a new facility being built at Ravenswood, West Virginia. A comparison of the chemical plants at Baton Rouge and Gramercy discloses a changing demand made upon the power and utility facilities in this type of plant.

Baton Rouge and Gramercy Plants

In 1942 one of the first 900 psig, 900 F industrial power plants was designed and built for the Aluminum Ore Company at Mobile, Alabama. This plant for producing high-pressure steam, electric power, and compressed air for production of alumina from bauxite was unique in that many central station features were incorporated in its design. This power plant went into operation in early 1942. Shortly thereafter Defense Plant Corporation ordered its duplication in a number of locations throughout the country.

The second plant of this design was located in Baton Rouge, Louisiana, to furnish power facilities for the alumina plant which has since been acquired by KA&CC. In 1952 power generating facilities of this plant were increased by the addition of three steam generating units and two turbine generators and the uprating of the three original boilers. This power generation was required for increased production of alumina to support the new reduction plant at Chalmette.

At Baton Rouge and Gramercy the chemical processes are basically similar but the demands upon the power facilities are different by reason of the developments during the five-year interval between initial operating plant dates. The Baton Rouge plant currently is rated at 800,000 tons per year and the initial plant at Gramercy will produce at the rate of 500,000 tons per year.

Philosophy of power plant design is influenced by the nature of the pattern of demand made by the process for power and steam and by the instantaneous ratio of steam flow to electric power demand.

The process comprises three similar units at Baton Rouge and two units for the anticipated plant at Gramercy. These process units are subject to scheduled outages in sequence during the year to allow for maintenance activities and consequently allows inspection and maintenance of certain of the associated power facilities. This permits a power plant design wherein minimum facilities can be installed and operated to take full advantage of the inherent high degree of availability of the power plant equipment. Turbine generators, boilers, feed pumps, deaerators, and associated equipment fall into this category.

The use of outdoor boilers and enclosed auxiliaries and turbine room was established at Baton Rouge and has been continued at Gramercy. At Baton Rouge the power demand is not large enough to require the use of all process steam through the turbines and consequently some of the high pressure boiler steam is bypassed around the non-condensing turbines (Fig. 6).

Fuel use is represented by about 9000 Btu per pound of aluminum oxide at Baton Rouge. Design improvements in the Gramercy Works process have reduced the fuel costs per unit of product.

At Baton Rouge, full steaming capacity can be maintained on the stand-by heavy fuel oil supply system. Gramercy design does not include a heavy fuel oil stand-by facility but provides light oil sufficient for one boiler to steam at about 100 M pounds per hour for 14 hr. This provision is necessary to maintain steam to the air compressors and to one turbine generator during a possible gas fuel transmission line rupture. Louisiana experience has shown fuel gas pipelines to be extremely reliable, however. Extremely high fuel supply continuity is available under an industrial contract.

Although power steam may not be available to process as result of an upset, compressed air service must be maintained. For this reason the reliable slow speed reciprocating type air compressors each rated at 5676 cfm are used and integrated within the power plant proper to enhance reliability. These compressors have about 98.75 per cent availability.

Baton Rouge has decentralized control facilities that prescribe several permanently stationed local operators and minimum communications.

The Gramercy Design

No attempt to design a unit system of turbine generators, boilers and auxiliaries at Gramercy was made because the process plant imposed somewhat disassociated demands for steam and power. A unit system does not allow the generous flexibility of power operations necessary in this type of facility.

Gramercy boilers are pressurized, turbo-flame type furnaces with combustion air supplied from turbine driven F.D. fans and are rated at 320,000 lb steam per hour at 900 psig and 905 F. Regenerative type air preheaters are employed. The Riley turbo-furnace boiler was selected so that pulverized coal could be used in the future. The F.D. fan turbines are supplied with blended steam from the associated boiler drum and superheater header so that these turbine drivers need only be rated at 600 psig and 750 F. The turbines exhaust to the 125 psig process steam header (Fig. 7). This equipment marks a decided design change compared with the 160,000 pounds per hour boilers at Baton Rouge where a balanced draft system is used. There the I.D. fans have motor-turbine dual drive, the air heaters are tubular type and only oil or gas fuel can be accommodated.

At Gramercy there is insufficient energy from the process steam through the turbines to produce the required amount of power and consequently condensing turbines were necessary to allow adequate power production flexibility. The Gramercy design allows the power plant to function completely independently of the process plant in times of upset or emergency. At Baton Rouge power plant operation, however, is entirely dependent upon the demands of the process plant with consequent lack of flexibility.

The forced filtered ventilation of the turbine and auxiliary bays have been added at Gramercy as a result of the experience at Baton Rouge where increased maintenance and clean-up costs have been attributed to the influx of chemical dust from the process.

Water Conditioning

The alumina production process generates condensate from evaporated water added to the raw materials in the process. Thus there is usually an excess of condensate available for boiler feed. However, this condensate is contaminated by the process in varying degrees for varying periods of time depending upon the process operations. Badly contaminated condensate is wasted instead of returning to the feed water storage tanks. Contaminants are mostly ammonia, caustic soda, aluminum hydroxide and silica; the condensate pH is always high and usually about 9.2.

Such water quality requires either water treatment ahead of the boilers or restriction of boiler steam conditions to a maximum of about 900 psig. In the Gramercy design it was found not sufficiently rewarding to use feed water treatment to be able to increase the turbine throttle conditions to 1800 psig and 1000 F.

Proven reliability of large size power equipment units has also influenced the Gramercy design. Large deaerators are used to suit the convenience of construction of the plant in two steps with one deaerator serving each step. Each 1,200,000 lb per hour deaerator supplies two steam driven turbine boiler feed pumps. A

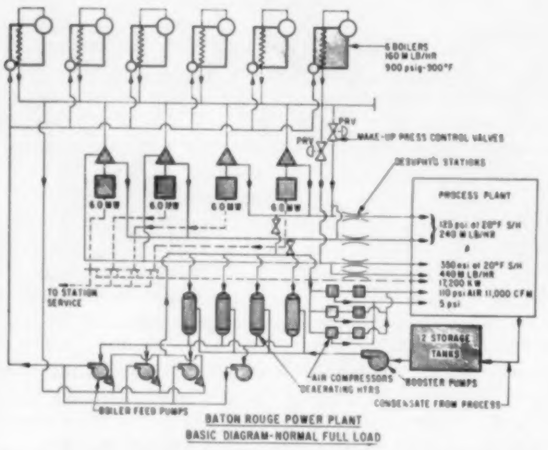


Fig. 6—Power demand in above plant is not large enough to pass along process steam through turbine so some is by-passed. Yet power plant operation depends entirely upon process plant needs.

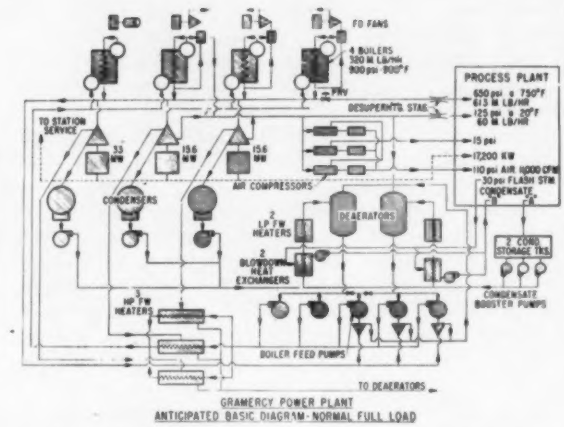


Fig. 7—Above design allows power plant to function completely without process flow in case of emergency. However, process steam flow through turbines gives insufficient energy hence condensers are used.

spare feed pump is provided and as the plant expands the use of the spare pump will be extended.

Feed water heaters are employed at Gramercy in order to improve the plain heat rate of the condensing turbine cycle. Waste heat is reclaimed from the process to serve as heating media in the low pressure heaters and turbine extraction steam serves to supply the high pressure heaters. In addition the 5–8 per cent boiler blow-down heat is partially recovered in a low pressure feed water heat exchanger. The inferior quality of boiler feed dictates a measure of continuous blow-down to maintain reasonable boiler water conditions.

At Gramercy the river pump house is an integral part of the ship dock at which bauxite is unloaded into the plant. The circulating water pumps delivering through steel pipes over the river levee onto the plant site supply water to the process plant and to the turbine-generator condensers. The condenser cooling system is a closed system where water is pumped back over the levee to the river after passing through the condensers. Vertical turbine type pumps are used at the pump house and a vacuum pump extracts non-condensables where the cooling water return line rises over the levee before discharging into the river below the level of normal low river stage.

Boiler water quality control at both Baton Rouge and Gramercy is critical because of the relatively high percentage of contaminants returning from the process plant. An inevitably high pH of about 11.5 results from employing only sufficient boiler blow-down to maintain boiler water total solids below 700 ppm and tends to cause foaming within the upper extremities of the boiler circulator tubes and in the drums unless it is closely controlled. However, practice has shown that it is possible to operate under these conditions without excessive maintenance and operating problems. Boiler waters of 12.0 pH quality are common during an upset in the process plant. Normally only sodium metaphosphate is added as internal boiler water treatment.

An advantage Gramercy will have over Baton Rouge is the recorded "total solids" and pH values of drum water for each boiler in the control laboratory adjacent to the control room. The power plant operators will be able to maintain close watch of the boiler water quality and adjust continuous blow-down rates and phosphate additions as the quality of returning process plant condensate changes. The phosphate feed will be by chemical pumps located in the control laboratory.

A Baton Rouge experience that has not yet resulted in specific design considerations at Gramercy stems from the high causticity suffered by the boiler water. Slow seepage of boiler water at the water tube seats and header hand hole plates occurs. The leaking sodium hydroxide sets up a highly corrosive cell as it is evaporated out of solution and sodium hydroxide "barnacles" build-up at the point of leakage. This has led to the rapid failure of many water wall tubes at the point of entry into steam drum and upper headers. The rapid deterioration of hand hole plate gaskets also has led to extensive leakage.

This maintenance problem has resulted in experimental seal welding of some water wall tubes at the boiler steam drum and headers at Baton Rouge. The Gramercy experience has yet to be known and will be met by measures based on the extended experiences at Baton Rouge.

Auxiliary cooling water is supplied through a closed cooling tower system to the various bearings, oil coolers, hydrogen coolers, cooling coils, and other coolers at both Baton Rouge and Gramercy. At Gramercy the temperature of the water leaving the cooling tower will be controlled between 80 and 90 F. This will be accomplished by automatically by-passing the returning cooling water around the tower. A steady supply water temperature serves to reduce the degree of operating adjustments within the power plant and minimizes the "sweating" action on cooling water piping surfaces due to the almost continuous high humidity of the atmosphere in Louisiana.

Influence of Process

It is possible to lose fuel supply to the power plant boilers without simultaneous curtailment of process steam to the process plant and without the power plant having the operational jurisdiction of closing off the

process steam lines quickly. A continuous drain of steam from the system can disastrously lower boiler pressure, cause extensive flashing within the boilers and possibly cause damage to the upper water tube areas due to over-heating. Gramercy will be supplied with trip valves in the process steam line so that the process plant can be isolated rapidly from the power plant. These valves may be tripped closed from the power plant control room or will trip automatically when both No. 1 and No. 2 main turbine stop valves are in the closed position.

The increase in the energy level of the higher pressure process steam at Gramercy as compared with Baton Rouge, coupled with no apparent improvement in the quality of condensate returning to the power plant, created design difficulties that only could be satisfied by the use of condensing turbines. The average annual thermal performance at Baton Rouge has been 4710 Btu per kwh and 1412 Btu per pound of steam at the boilers. At Gramercy it is anticipated as 11,800 Btu per kwh and 1300 Btu per pound of steam at the boilers. It is obvious that the economics of this industrial power plant application is changing for the worse and design changes must be made in the future to off-set this trend. However, Gramercy power is still more than competitive with utility power because of the use of controlled extraction of steam from the turbines, minor incremental boiler and auxiliary capital costs attributable to the turbines, the high and steady load factors involved, and the lack of extensive power transmission lines.

Additional Facilities

Gramercy has a central air conditioned control room with extensive communications under the control of a senior operator. No local control panels are provided except for the generator hydrogen cooling systems which are located on the lower operating level near the respective hydrogen service equipment. Only a few locally mounted gage panels will be provided.

The central control operator will be able to monitor and control the master boiler functions, turbo-generator functions, river pump house functions, steam pressure reducing stations, desuperheating stations, power distribution, emergency diesel engine generator, domestic water plant, auxiliary cooling water tower, main condenser functions and boiler feed pumps.

A pneumatic control and instrumentation system has been used wherever possible because of the firmness of the air supply in this plant. Ample annunciation in general terms is provided so the control operator can direct his assistants to trouble spots for inspection and remedian operation by an extensive P. A. system.

For emergency operations a 1000 kw diesel engine generator is provided as a completely independent self-sustaining unit in order to supply start-up power in event of a complete outage of the power plant. Such an arrangement is less costly than supplying and operating an emergency power tie-in with a local utility. The diesel engine generator will allow energizing these units:

One condenser cooling water pump
All turbine turning gears
All hydrogen seal oil pumps
One auxiliary cooling water tower cell
One condenser condensate pump
Fuel oil pump
Emergency lighting
Power plant dc batteries which supply all annunciators, circuit breaker controls and selected vital solenoid operated control functions.

Upon loss of normal supply, the power delivered by the diesel generator can be switched manually into the power plant power service at 2400 v, and the selected vital drives then energized.

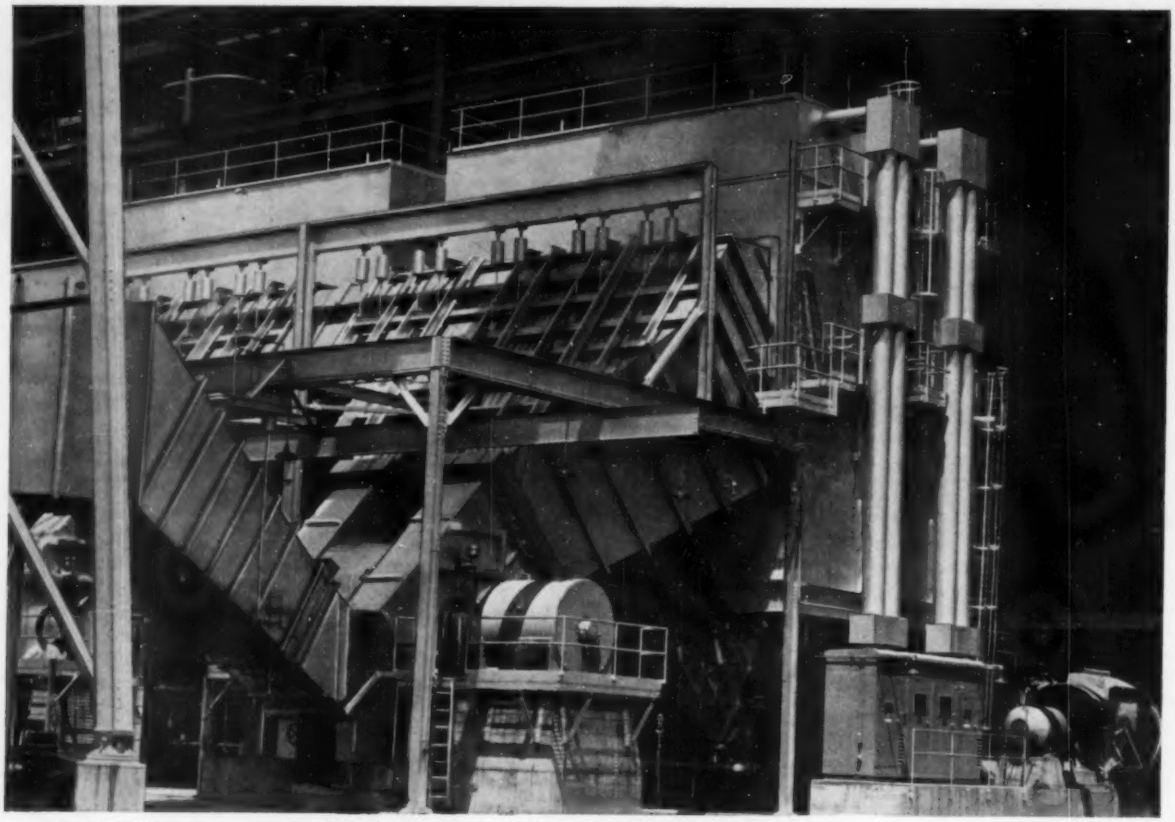
Conclusions

Generally, we are in the position of having to remain alert to all trends and innovations within the power and allied industries, fuel supply industries, and power operational maintenance practices.

Our energy uses are considerable and we are faced with the need to employ larger and more efficient units of thermal conversion to produce both steam and power. Technically, we have a great deal in common with medium-sized public power utilities but our philosophies must be established to satisfy shorter "pay-out" periods coupled with the ability to seek low-cost fuel areas or systems.

Process plants have grown considerably in size and output since World War II. Industrial power plants have had to keep up with this growth, and from all indications, it appears that this growth will continue with power plants becoming larger, more complicated.

Industrial utility organizations have become so vital they now merit recognition and prestige equal to the associated process production organizations of which they were once only a part. Now they contribute to the end product—technically and economically.



For this Midwest power station, Westinghouse induced draft (center) and forced draft (right) fans move a total of 92,500,000 cubic feet of air and gas every hour, every day.

8 All-Weather Westinghouse Fans Supply Mechanical Draft to Meramec Station of Union Electric

Air-cooled bearings, welded steel construction resist elements

Eight Westinghouse Turbovane mechanical draft fans with vane control supply draft to the two boilers of the Meramec Station of Union Electric Company located in St. Louis, Mo. Installed outdoors where they are exposed to the varying elements, these fans perform their part of a vital power-generating job with only routine maintenance.

Four of these fans are Turbovane forced-draft type arranged double width, double inlet. The other four are Turbovane induced-draft fans with radial-tipped blades and erosion-resistant wheels. Vane control on all fans allows instantaneous regulation of air volumes to meet changing steam demands.

For power generation—or for any other air handling job—check on Westinghouse-Sturtevant apparatus today. Let the industry's most complete air handling line *put air to work* for you—efficiently, economically. Call the Westinghouse-Sturtevant specialists located in your area or write: Westinghouse Electric Corporation, Sturtevant Division, Hyde Park, Boston 36, Mass.

Located at the heart of power generation at Meramec, four Westinghouse forced draft fans supply 150,000 cfm each, at 11.3 inches water gauge while operating at 1180 rpm. These are teamed with four Westinghouse induced draft fans handling 235,500 cfm each, at 277°F and 17.1 inches water gauge while operating at 700 rpm.

WESTINGHOUSE AIR HANDLING

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J-80417

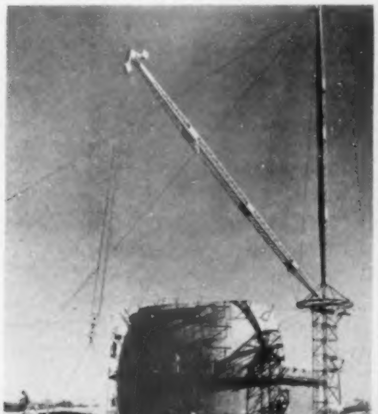
EBWR Goes on the Line

FEBRUARY 9, 1957, will stand as a date to be remembered in the historic development of atomic energy as a source of electric power. At 3:01 p.m. CST, Representative Carl T. Durham of North Carolina, chairman of the Joint Congressional Committee on Atomic Energy, in the presence of Admiral Lewis L. Strauss, chairman of the U. S. Atomic Energy Commission, activated a switch which caused the Experimental Boiling Water Reactor to take over the electric power supply for the Argonne National Laboratory, located about 24 miles south of Chicago.

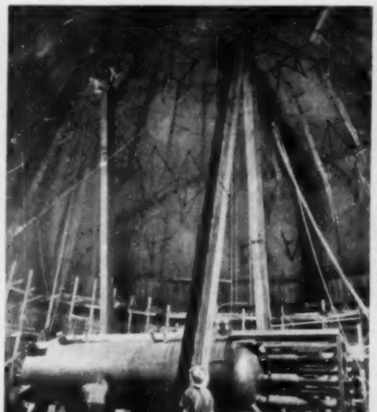
Part of the AEC Experimental Power Reactor Program, the EBWR power plant is designed to produce 20,000 kw of heat and 5000 kw of electricity, which is the minimum capacity considered necessary to permit sound extrapolation to large-size central station plants. Construction work on EBWR was begun on May 27, 1955; the reactor first achieved criticality on December 1, 1956 and reached its rated heat level of 20,000 kw on December 28. Power was first produced in check-out tests on December 23, and rated power level was reached on December 29, 1956.

Role of EBWR

EBWR holds a very important place in the AEC Experimental Power Reactor Program, not only by virtue of its being the first such reactor to be completed, but also because it offers a promising approach to economical nuclear power. The simplicity of the boiling reactor design, offering the possibility of avoiding heat exchangers, and the inherent safety characteristics of the system, give the EBWR a special significance in the development of nuclear power. In addition to eliminating an external heat exchanger, a boiling water reactor



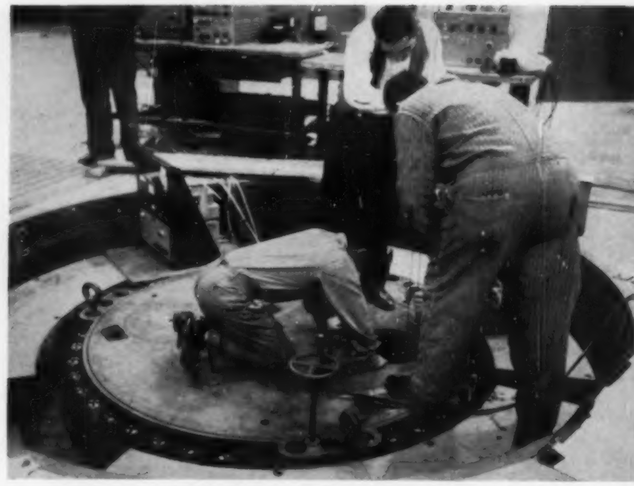
Construction of containment vessel; height—119 ft; diameter—80 ft



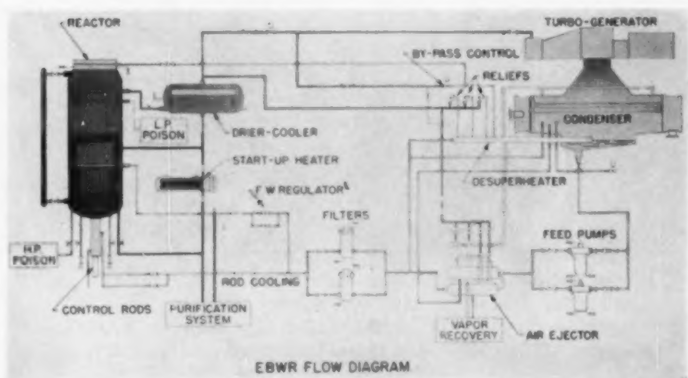
Reactor pressure vessel being moved into position in containment vessel

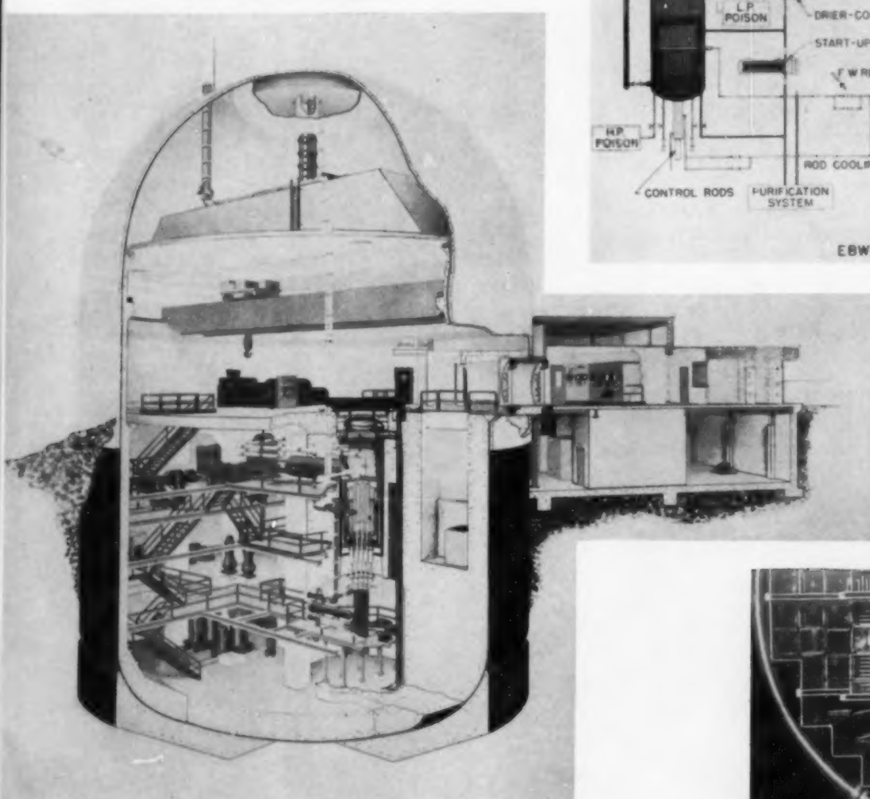
Lowering reactor core structure into 31-ft high pressure vessel

Loading fuel assembly into reactor; beginning with some 40 elements, two to six were added each time until criticality was reached at 81 fuel rods

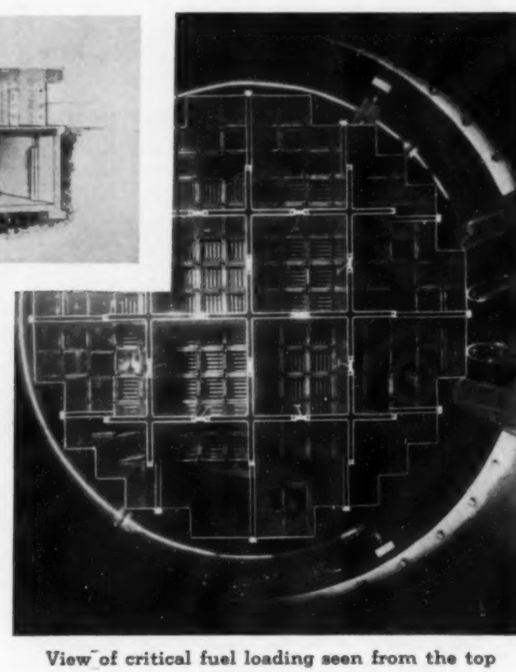


During loading of reactor fuel, eccentric shield plugs are used to position the shield opening over the desired core location. Note use of concentric and eccentric gears to position elements

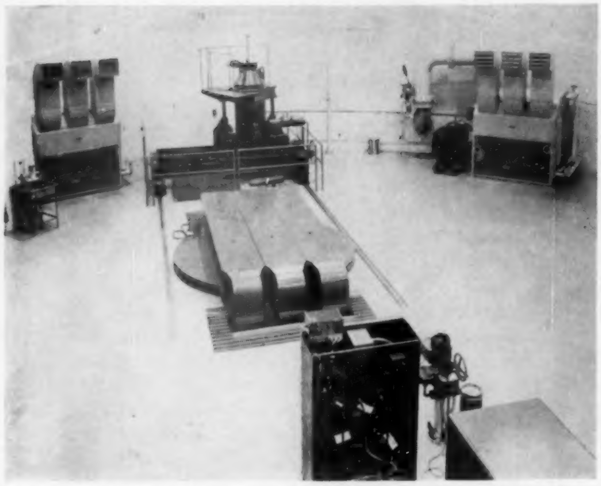




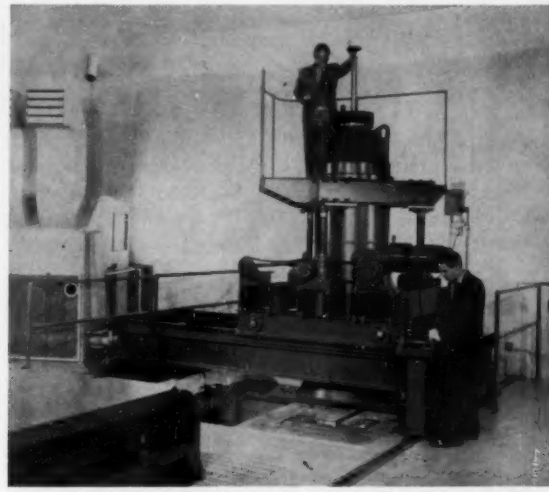
Perspective view showing circular traveling crane above turbine-generator; control room and electrical bays to right; reactor in center and auxiliaries in levels to left



View of critical fuel loading seen from the top

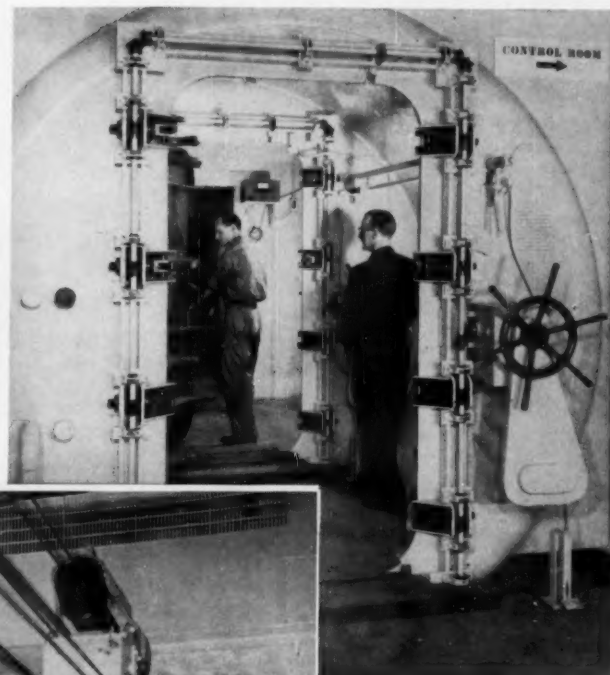


Multiple steel beam on top of reactors guarantees that fragments will be deflected downward in emergency

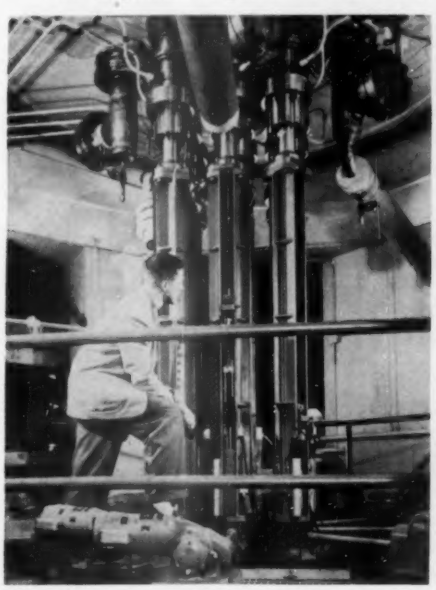


Fuel handling equipment to transfer intensely radioactive fuel elements from reactor to water-filled pit

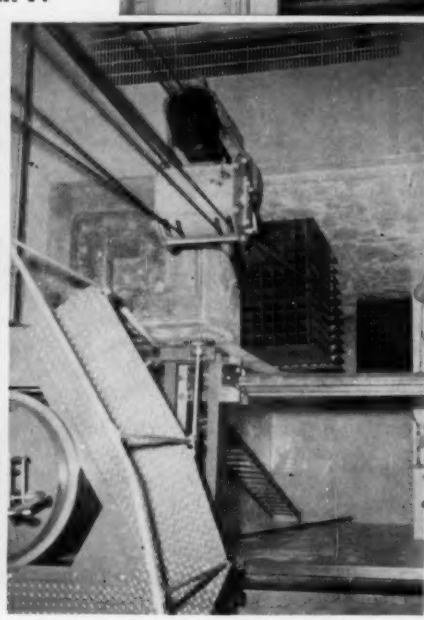
Scene during startup of reactor on February 9; Joseph N. Harrer, EBWR project engineer, described process to guests on closed-circuit TV



One of the main airlock doors in the gastight power plant building. During normal operations one of the doors is latched in closed position



Control-rod drive mechanisms below reactor



View of fuel storage tank which is normally filled with water to hold irradiated fuel elements in an upright position when removed from reactor for replacement

has the advantage that the steam pressure and temperature can be as high as those in the reactor vessel, thus improving the total thermal efficiency of the plant. Conversely, a cheaper reactor vessel can be designed for a given steam pressure. For example, if a steam pressure of 600 psig is desired, a boiling reactor need only withstand this pressure, whereas a pressurized water reactor may have to be designed up to 2000 psig.

One important feature of this type is that an increase in demand leads to a lower reactor pressure, an increase in the steam volume, and a reduction in the reactivity and power level. The reactor thus has good nuclear stability. This feature, although contributing to the safety of the reactor, tends to lower, rather than to increase power to meet rising demand.

Type of Reactor

EBWR is a thermal-type reactor; that is, the neutrons produced by fission are slowed down by moderator. This makes it possible to use uranium containing a low percentage of U^{235} as fuel. The reactor fuel is a mixture of natural and slightly enriched uranium. Light water serves as moderator and coolant. The reactor is cooled by the water as it boils and circulates through the core by natural convection, Later, forced circulation pumps may be used to increase the power output and to study the effect of forced circulation on reactor stability. It is planned to substitute heavy water for light water and to install a core more suitable for a heavy water moderator after the desired operating experience is obtained with light water.

Pressure Vessel

The reactor proper is contained in a pressure vessel that is 7 ft in diameter and 23 ft high internally, and which has steel walls $2^3/_8$ in. thick. This vessel is mounted in a heavily shielded reactor well so that the top head of the reactor is just below the main (ground level) floor of the power plant building. The vessel is supported on its upper end by lugs resting on springs which in turn rest upon a steel frame attached to steel columns embedded in the concrete basement floor. The inner surfaces in contact with the reactor water or steam are clad with stainless steel. When the reactor is operating, the heat generated in the vessel wall by nuclear radiation will raise the temperature of the metal to 500 F, which is above the saturation temperature (489 F) of steam at 600 psig. The vessel wall is protected from excessive heat generation by a boron-stainless steel thermal shield.

Core of Reactor

The core inside the pressure vessel consists of fuel assemblies and control rods fitted into a support and shroud structure that is bolted to the bottom of the vessel. The support plate and shroud structure will hold up to 148 fuel assemblies within a five foot diameter. The present core, about four feet in diameter, consists of 114 assemblies, of which 106 assemblies contain enriched (1.44 per cent U^{235}) uranium and 8 contain normal uranium. There is a total of 6.1 tons of uranium averaging 1.4 per cent U^{235} in the core. Dummy assemblies are used to fill out the core to the five foot diameter. The space between the core and the vessel wall is the downcomer space for the water as it circulates. The core shroud structure serves the triple purpose of holding the upper ends of the fuel assemblies, providing additional riser height above the assemblies to enhance natural circulation, and serving as the guide for the nine control rods moving within the core. The components in the active region of the core are made of zircaloy-2, a metal which does not absorb neutrons readily and which has good corrosion resistance properties. Components outside the active region are fabricated from stainless steel.

Fuel Assemblies

Each fuel assembly is $77^5/_8$ in. long by $3^3/_4$ in. square. An assembly is composed of a lower locating end fitting, six fuel plates, two side plates and a top fuel handling fitting. The fuel plates are uranium-zirconium-niobium alloy sheets manufactured in two thicknesses and two enrichments. One plate is 54 in. long, $3^5/_8$ in. wide and 0.214 in. thick; the other is the same length and width but is 0.279 in. thick. Both normal and 1.44 per cent enriched uranium are used in plates of both sizes. The uranium alloy is clad with zircaloy-2 sheet by a hot-rolling process. Nominal cladding thicknesses are 0.020 in. over the plate faces, 0.125 in. over the edges and $1^1/_2$ in. over the ends. The six fuel plates are arranged parallel to one another with water channel space between adjacent plates. The side plates, measuring $61^1/_2$ in. by $3^3/_4$ in., are made of zircaloy-2 sheets.

Control Rods

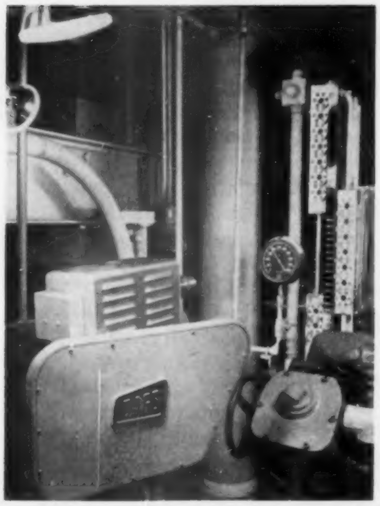
Nine control rods of two types are used in the reactor. Hafnium is the absorbing material in five of the rods, which are located in the most effective (central) positions. The other four rods are made from stainless steel containing 2 per cent boron.

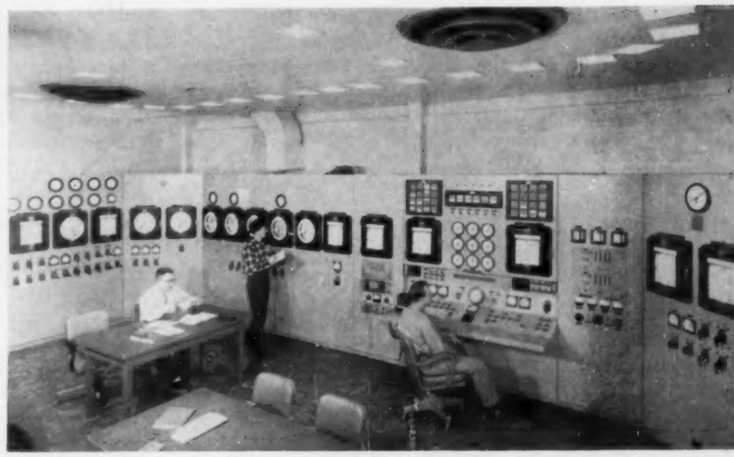
Hafnium-zircaloy-2 control rods are $^1/_{16}$ in. thick sheet metal bent into angles and spot welded together forming cross-shaped sections 10 in. by 10 in. by $^1/_8$ in. thick. The upper 46 in. of the rod are hafnium, the middle 58 in. are zircaloy-2 and the lower 71 in. are stainless. The rod weighs 97 lb. The boron rod has essentially the same dimensions, except that it is $^1/_4$ in. thick, and weighs 141 lb.

Although control rods are installed and removed from the top, they are operated from the bottom through labyrinth seals on the lower ends of thimbles attached beneath the pressure vessel. During operation the absorber section of the rod is driven up out of the core followed by a zircaloy-2 follower section which replaces the absorber in the guide channel. Release of the rods and rapid insertion for reactor shutdown takes place in less than one second. Rods are inserted by springs, gravity, and the pressure in the reactor vessel, the springs serving to get the rods into motion quickly.

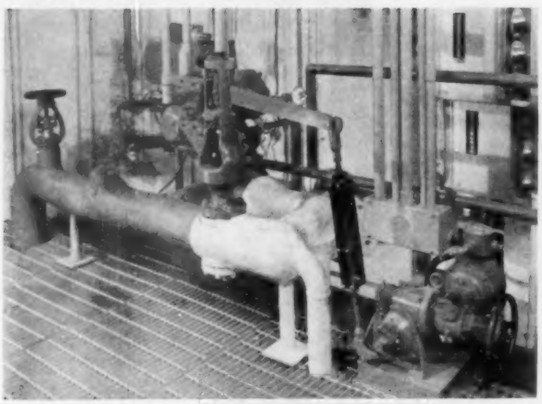
Shielding and Insulation

The shielding was designed to meet the requirements for operation with a 40-mw heavy water core. In addition to the shielding afforded by the water and the vessel walls, the vessel is surrounded by a 3 in. thickness of stainless steel wool insulation, 3 in. of air space, and a steel cylindrical tank which serves as an inner form for shielding. The total thickness of radial shielding is 8 ft $3^1/_2$ in.

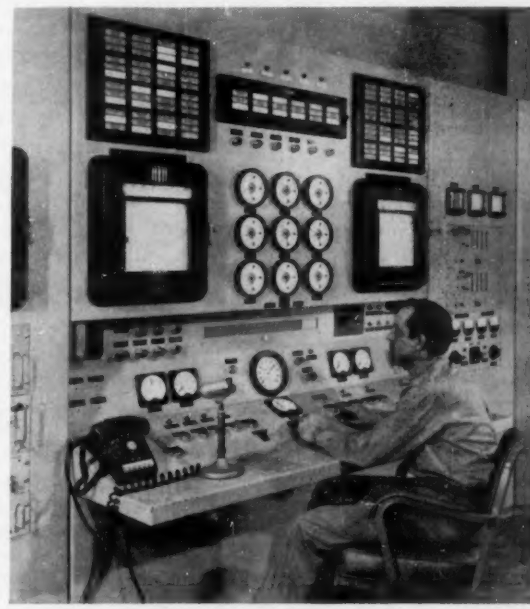




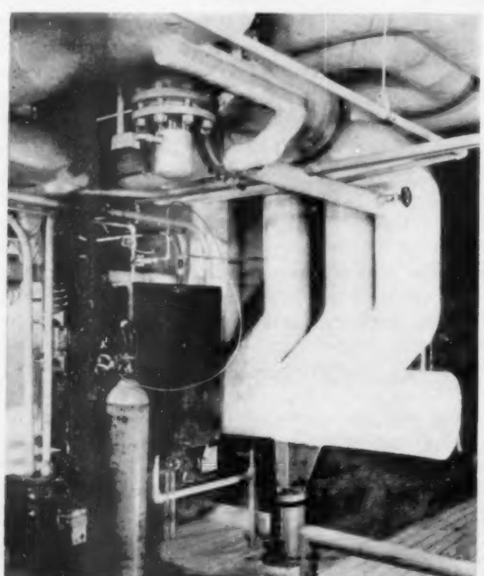
Left, remote television camera transmits view of reactor-vessel water level and pressure to central control room, right, shown during operation



Feedwater regulating valve located adjacent to remote television camera on one of the lower plant levels



John Daniels, pile operator, at the reactor controls



Hydraulically operated steam bypass valve shown at left and desuperheater in background. Former maintains constant pressure under variable load

Reactor Operation

During operation, cold feedwater at 110 F is pumped into the reactor vessel where its temperature is raised to 488 F at a pressure of 600 psig. At 20,000-kw core power, the corresponding steam generation rate is 60,600 lb per hr, which is reduced to 60,000 lb per hr with the reactor water purification system in operation; about 150-kw heat is rejected by the purification system. Approximately 35 per cent of the heat of fission is expended in raising the cold feedwater to saturation condition at 488 F and the remaining 65 per cent forms steam.

The steam rises through the vessel to the steam collection ring at a rate of 0.39 ft per second. Although the total impurities in the reactor water are kept down by the purification system, some irradiated impurities will be carried over. To minimize this carryover, the

steam collection system is designed to avoid the entrainment of water droplets. A de-entrainment factor of $^1/_{10,000}$ is expected, based on laboratory tests and Borax-III experience. This means, the ratio of non-gaseous activity in water outside the reactor to that inside the reactor is $^1/_{10,000}$.

Power Generation

Power generation itself is not a primary objective in the EBWR plant, since the feasibility of generating electricity with pressurized steam requires no verification. However, many of the questions on which more information is needed are associated with the direct coupling between the reactor and the power generating equipment; hence the need for a complete power plant. Prominent among these uncertainties are radioactivity and reactivity feedback effects. Corrosion, erosion, leakage, and water quality control must also be studied.

The properties of steam generated in a nuclear reactor differ from those of ordinary steam in two respects which affect power plant design. Reactor steam is slightly more corrosive because small amounts of water are dissociated into hydrogen and oxygen, and the free elements make the water more corrosive. The corrosion and erosion particles become radioactive as they pass through the reactor core and some of the particles will be carried over with the steam. In the future when heavy water is used, the dollar value of the heavy water itself will make conservation of even minute quantities of steam and water significant.

In the power plant, saturated steam at 600 psig and 488 F is passed from the reactor vessel to the turbine through a steam dryer. The steam dryer, equipped with cooling coils, may also serve as an emergency cooler. Steam in excess of that demanded by the turbine in response to generator load is bypassed through a desuperheater directly to a condenser.

The reactor is normally operated at constant power and steam flow rate. In order to minimize the regulation of reactor power with fluctuations in electric power demands, all excess power is removed as steam bypassed directly to the condenser. The steam bypass valve can be set for automatic control. With a fixed steam flow, an increase in generator load automatically causes a diversion of more steam to the turbine. If the load increase is too great the only recourse is to regulate the reactor. When the load is decreased the bypass valve automatically directs excess steam to the condenser.

A start-up heat exchanger is used to preheat the reactor water to 325 F prior to withdrawal of the control rods. Laboratory steam at 190 psig and 378 F surrounds the tubes containing reactor water. The water within the tubes boils at atmospheric pressure until the reactor temperature reaches 212 F. Then the temperature and pressure rise correspondingly. The flow of the reactor water is by natural circulation.

Reactor Control

The entire EBWR facility—the steam plant as well as the reactor—is operated by remote control. The apparatus in the control room is connected to that in the plant by means of about 1200 electrical cables.

The reactor is controlled by movement of control rods driven by mechanisms located beneath the reactor. A complicated interlock system requires that 15 conditions must be safe before the reactor can be started up. Similarly, if the limit set on any one of these conditions is exceeded when the reactor is operating, it will be automatically shut down. When all 15 conditions are in order, the operator has full command of the control rod operation and can control the reactor power within the limits of the safety interlock system.

The nine control rods at operating conditions have a combined strength greater than the amount of k (reactivity change) to be controlled. Failure of one or even two rods will not create a dangerous situation. The reactor will not be operated with less than two more than the number of rods required to control all available excess k. Failure of the rods to reduce reactivity is backed up by a boron solution injection system. The system is arranged so that if the necessary number of control rods do not fully enter the core within two seconds from the time the signal is given, the prepared solution of boric acid is injected quickly under high pressure.

Even when the reactor is shut down, delayed beta and gamma radiations given off by fission products represent a significant amount of heat. For example, seven hours after shutdown of EBWR the rate of heat generation in the fuel elements is still one per cent of the value when the reactor is operating at full power. If all water should be lost from the core, the fuel elements would overheat and eventually melt. A great number of safety devices have been incorporated in EBWR to prevent this from happening.

Shutdown heat is normally removed by circulating a small quantity of reactor water through heat exchangers in the reactor water purification circuits. Two such circuits are provided to guard against failure.

Engineering Design

The engineering design of the Experimental Boiling Water Reactor facility was the result of the combined efforts of the Argonne National Laboratory and Sargent & Lundy. Argonne developed and supplied the basic nuclear information required to enable Sargent & Lundy to prepare the specifications for nuclear and steam plant equipment which could be purchased commercially. The core, including fuel elements, and control rods with drives were developed and fabricated by Argonne National Laboratory. The basic plans for the remainder of the plant were developed in cooperation with the Argonne by Sargent & Lundy's regular staff, since the work to a large extent was similar to the design of a conventional steam generating plant. While there were certain new and additional designs required because of special nuclear considerations, these were resolved by application of conventional engineering practices.

Principal Equipment Suppliers

Turbine generator, surface condenser, reactor recovery system, steam bypass control system, feedwater pumps, circulating water pumps, diesel-generator set, and principal electrical equipment—Allis-Chalmers Manufacturing Company.

EBWR pressure vessel, steam dryer—emergency cooler—Babcock & Wilcox Company.

Containment shell, demineralizing equipment—Graver Tank & Manufacturing Company.

Control panels and instruments—Leeds & Northrup Company.

General contractors—Sumner Sollitt Company, Chicago.

The 1957 Nuclear Congress

JUST as this issue was going to press the 1957 Nuclear Congress, jointly sponsored by some 24 technical societies and coordinated by the Engineers Joint Council, was in session, March 11–15, at the Convention Hall, Philadelphia, Pa. The meeting was actually a combination of four major activities: (1) the jointly sponsored sessions running from March 11–14, (2) a two-day session on hot laboratories dealing with radioactive materials, (3) a general industry conference on atomic energy and (4) an all encompassing International Atomic Exposition.

Over 140 technical papers dealing with such topics as establishing safe limits for human exposure to radioactivity, production of nuclear fuel, design and construction of atomic installations, use of isotopes in medicine and industry were scheduled for presentation over the four-day period of the Joint Congress. About forty special papers were planned for the last two days of the session as part of the 5th Hot Laboratories and Equipment Conference. The National Industrial Conference Board during these same two days were holding their 5th Atomic Energy in Industry Conference revolving around some 12 or more panels. The Atomic Exposition featured the exhibits of over 100 industrial and governmental organizations.

The abstracts below are based upon all preprints available up to the time of our going to press. If attendance at the Congress reveals additional material of interest to our readers we shall publish their abstracts in April.

Competitive Nuclear Power

Harlan W. Nelson and **W. R. Keagy, Jr.**, Battelle Memorial Institute, in a paper, "The Economic Background for the Competitive Development of Nuclear Power," made the interesting declaration that the first and most substantial single civilian application of nuclear power reactors will probably be for the generation of electricity. Extensive applications for process heating, vehicle propulsion, and space heating are not expected to be developed until much later. Consequently, a great amount of business, industrial, and financial interest is focused on applying nuclear energy to electric power generation.

There is little justification for any belief that nuclear-powered plants can become established on the basis of prices rising sharply in the next twenty years. Even for the natural gas-consuming areas, where gradually increasing costs are foreseen, it will take some time for fuel costs to reach even the present levels of Middle Eastern areas. Improved technologies in mechanical mining in the coal-producing areas, with resulting increased output per man day, are expected to be important factors in preventing coal costs from rising at an abnormal rate in spite of higher labor costs. Lower cost transportation by belt line or hydraulic means may also become a factor in stabilizing coal costs.

It has previously been shown that the cost of fuel consumed at thermal generating stations has remained generally stable since 1939 despite approximately doubled fuel prices and inflationary trends. The reason for this has been improved efficiencies and technologies in the furnace-boiler and in the turbine-generator systems. The overall result has been that the station heat rate has consistently decreased. A common yardstick used in the designation of efficiency of fuel utilization is the weight of coal, or coal equivalent, required to produce a net kilowatt hour of electric energy. The rate now stands at about 0.96 lb per kwhr, whereas 3 lb were required to produce a unit of electric energy in 1920. As we approach closer to the practical limits of heat rates (the number of Btu required to produce a kwhr), improvements at economical cost, however, will become increasingly difficult to achieve.

Combining all factors of production and fixed charge costs for modern generating stations in 1954, the *Electrical World* Survey shows the cost of producing a net kwhr of electricity to be in the range of 6 to 7 mills. Average cost was 6.3 mills per kwhr. The extremes range from a low of 3 mills for an outdoor plant using low-cost natural gas to a high of 12.5 mills, reflecting the combined effect of low plant factor and high fuel costs. Sixty per cent of the reporting stations had total energy costs of 7 mills per kwhr or less.

The estimates and analyses made by the McKinney Panel are extremely useful in demonstrating how and under what conditions nuclear power in the U. S. might become competitive with power from conventional sources. However, as a tentative timetable to indicate when such developments may be expected, the estimate of the Panel must be regarded as being much more speculative.

The nuclear power costs assumed are those recommended to the Panel by numerous experts called to testify upon the matter at the end of 1955. Their judgment must be accepted as the best available at that time. Yet these same experts estimated nuclear power costs for 1960 at about 10 mills per kwhr, and there is the expressed opinion in some quarters that this estimate may be somewhat on the optimistic side.

A number of full-scale power reactors are either under construction or planned, and there is a wide variance in the plant costs at which they have been quoted. At one extreme is the AEC-Duquesne Shippingport reactor plant having total costs variously estimated at from \$85 million to \$107 million. Such estimates include heavy expenses for research and development of a pioneering nature. At estimated construction costs of \$38 million, however, and assuming 100,000-kw eventual capacity, this station still is expensive at \$380 per kw. The same is true of the PRDC-Detroit Edison fast breeder with estimated total costs of \$45 million and a capacity of 100,000 kw. Construction costs for the reactor portion alone are expected to be \$290 per kw exclusive of site and turbo-generator costs.

In contrast to these, much lower costs have been indicated for some other large reactor plants. The Commonwealth Edison Dresden Station is expected to cost \$45 million plus an undisclosed amount of research and development effort contributed by the General Electric

Co. However, construction costs alone are estimated to be of the order of \$30 million which, for the 180,000-kw plant, figures out at a very attractive \$167 per kw. Most other installations, such as the pressurized-water reactor for Yankee Atomic Electric Co., are expected to fall within the \$250 to \$300 per kw range. Figures quoted for Consolidated Edison's Indian Point Station are difficult to interpret because of the influence of the oil-fired superheater. However, Babcock & Wilcox estimates that a straight 100,000-kw pressurized-water thorium converter plant could be built for \$290 per kw.

Figures such as these are not particularly meaningful, since it is difficult to separate construction costs from research and development expenses. Also, these plants are developmental in nature to a varying extent and, therefore, more costly than if they were built solely for power production at minimum cost. In view of this fact, and considering the amount of experience to be gained over the next three years and the economies to be achieved in larger plants, the estimate made by the McKinney Panel for plant costs to range from \$200 to \$240 per kw by 1960 does not appear to be unreasonable. Neither do the estimates for plant costs in the range \$175–\$205 per kw by 1970 seem unrealistic.

The situation was effectively summarized at the 1956 meeting of the Atomic Industrial Forum by AEC's U. M. Staebler when he said, "Results of all economic studies made to date are extremely sensitive to the particular assumptions made to fill the gaps left by missing facts. No one really knows what nuclear power will cost in the plants being built today." If this is true, then how much more difficult is it to predict or to estimate what nuclear power will cost in 1960, in 1970, or in 1980? And who can venture to say with any assurance when these costs will be reduced to 7 mills per kwhr?

Equipment Needs

The considerations and problems encountered in making available steel valves suitable for the peculiar conditions of nuclear power plants prompted the paper. "On the Quality Requirements for Steel Valves for Nuclear Power Plants," by **J. J. Kanter,** Crane Co. Briefly these requirements for the steel valves currently procured for nuclear power plants range from the standards generally recognized in power piping practice to those presenting a challenge to the industry. This range of requirements seems dependent on numerous considerations which differ with each reactor concept employed and the attendant hazards or consequences of malfunctioning of piping components. In short, there are no valve standards which can be considered unique and adequate to this field. As experience is gained and the more practical systems emerge, however, the production of nuclear piping should become a more familiar field, and it is to be expected that piping components utilizing less critical materials and designs lending themselves to economical production will emerge.

Present day problems are generally most acute where "primary loop" valves are involved. Upon the valves controlling the flow of a primary fluid special attention is given to all of the possibilities of failures or malfunctioning which might result either in the spreading of radioactive fluid or the loss of liquid cover of the fuel elements in the case of shutdown or reactor scram. The fluids to be contained, depending upon the reactor system, each with its own set of peculiar problems, include pressurized demineralized light or heavy water, wet saturated steam, liquid sodium or alloys of sodium-potassium, acid solutions of fissile materials, liquid phenolics or even molten bismuth or sodium containing fissile metals and fission products.

The problem of sealing valve stems against leakage perhaps is pre-eminent in the consideration it has received in the design and specification of primary loop valves. Systems for safeguarding against stem leakage to ambient utilize special provisions beyond ordinary packing glands, such as bellows, canopies, labyrinths of sealing rings, or even frozen seals of the fluid itself (as, for instance, sodium). Where canopies are used it is necessary to contrive remote operating mechanisms such as hydraulic cylinders or magnetic controls. Since bellows operation depends upon the elastic range of the bellows materials, the range of movement, where many cycles of operation are essential at elevated temperature, must be restricted leading to inordinate size of this component. Since satisfactory packing rings are generally of organic materials, cooling provisions on the packing gland must be provided in the designs where the fluid temperatures are excessive.

For each type of reactor the primary loop piping presents a different corrosion problem. In the case of the water-cooled reactors the reactor radiation provides a constant source of dissolved oxygen which, together with decomposition products, are factors in steel corrosion. Since reactor piping in general must provide for long operation, the accumulation of corrosion products carried from piping to reactor is intolerable and thus the pipe and valves must be corrosion resistant materials. In the case of liquid sodium heat transfer, there also exists a problem of attack upon the steel and the nickel-chromium austenitic steels are deemed necessary to resist it. Where liquid bismuth is the medium, there are mass transfer considerations and chromium-molybdenum ferritic steels have given the most favorable performance characteristics to date. Perhaps the most extreme piping corrosion is that to be contended with in the aqueous homogeneous systems, where highly resistant lining materials are sought. The organic material reactors using phenolic liquids do not present a special corrosion problem in the piping and apparently carbon steel is a satisfactory material for this system.

Because of the critical function of these valves much attention has been given by reactor plant designers to the various fabrication and material alternatives available in the manufacture of these parts. It might be said that each of these alternatives has a place and no one technique of valve manufacture is universally to be advocated for all situations, whether it be forging, casting or weld fabrication. Where large valves are required steel castings are perhaps the most economical choice and are widely and successfully used. Although forgings have been procured at considerable expense for large valves in certain of the more critical and exacting installations, reactor designers have agreed that steel castings are satisfactory and on numerous counts superior.

Apprehension over the integrity of steel valve components seems to stem principally from concern over the possible damaging influence of thermal cycling and

thermal shock. The seriousness of such effect again is not uniformly pertinent to all types of reactor systems, being functions of the degree and velocity of temperature change as well as the thermal properties of the fluids contained. For instance the thermal shock concern in liquid sodium systems are greater than with water systems. The materials of construction themselves are pertinent factors where thermal shock is a factor since high thermal expansivity and low thermal conductivity can aggravate the transient stresses which attain during period of temperature change. Any kind of "stress-raiser" in a metal section may be suspect as a source of eventual deterioration of a component subject to repeated and frequent thermal cycling as may be the case for primary loop piping. Hence, forgings containing flakes, castings with hot tears, heat-affected weld zones with microfissures, weldments with incomplete penetration, as well as design with sharp changes in section or other sources of stress concentration are all suspect in such service.

It is generally agreed that well made steel castings are quite as acceptable for primary loop applications as are forgings, although apprehension seems to exist over the porosity inherent to steel casting. Weld repair has become a recognized and accepted procedure in the fabrication of steel castings for many exacting services, and its use should not dismay the designer of nuclear power piping. Its use in the preparation of any component for critical service is dictated by nature of the phenomena whereby metals become solids upon cooling whether the product be an ingot for conversion to a forging or a shaped casting intended for a valve body. In the case of the valve, the foundryman is confronted by certain limitations in the uniform feeding of adjoining sections of varying size. By skillful risering, gating and pouring technique casting defects may be either controlled and minimized at unobjectionable locations or at least be held to a magnitude practicable for location and repair by welding.

The surface of valve parts for many of the loops is a special requirement. The rough forged or "as cast" surface must be removed by machining, grinding or filing, both inside and out, a common requirement being 124 RMS finish. This requirement becomes a painstaking one when applied to the inside surface of some of the parts.

The heat treatment of valve parts for primary loop applications requires some special consideration, particularly in the case of the austenitic nickel-chromium steel castings. Unlike ferritic carbon and low-alloy steel castings, heat treatment does not confer grain refinement.

Reactor Design

Michael Silverberg, Ford Instrument Co., selected for his topic "Gas Coolant for Nuclear Reactors." The closed-cycle gas-cooled reactor, according to Mr. Silverberg, has enjoyed a considerable upsurge in popularity within the past year or two. The Atomic Energy Commission and the Maritime Administration have sponsored studies for the application of the gas-cooled reactor to the propulsion of a giant tanker. The Commission has also investigated the use of gas-cooled reactors to supply commercial nuclear power. There are, of course, military applications, and these appear to have been given the greatest attention to date. The Commission's Gas Cooled Reactor Experiment, to be constructed at the National Reactor Testing Station removes this reactor concept from the pencil and paper category and brings it that much closer to realization. The experiment is designed primarily to provide information concerning military uses but some data of value to commercial nuclear power interests should also result.

In this connection, it is clear that military and civilian reactor objectives are usually widely separated. There are a number of requirements of a military power plant that simply cannot be evaluated in terms of cost whereas all commercial power plants generally can be reduced to a dollars and cents basis. This is the basic difference between the two applications. For this reason two independent development programs are necessary.

The closed-cycle gas-cooled reactor is unique in many respects. Not the least of these is the fact that it utilizes a power plant that, as yet, has not been completely proved. This is in contrast to existing nuclear power plants where the prime mover and associated equipment have been of conventional design with only minor modifications to suit the situation at hand. There is some information available today concerning closed cycle turbine operation but it deals with air as a working medium whereas most gas-cooled reactor designs propose the use of helium or nitrogen. Then, the author asked, why compound the problem by trying to marry a reactor to a power plant where both are in the development stages? The answer Mr. Silverberg gave is that the advantages of one complement those of the other so very well. Closed cycle turbomachinery makes possible part load operation at constant working temperatures and efficiency which is certainly desirable from the reactor point of view. Moreover the single closed loop provides the following advantages. The maximum turbine inlet temperature and hence maximum efficiency is achieved for a given peak reactor temperature. There are no heat exchangers to drop the operating temperature. Secondly, the release of radioactive gases to the atmosphere is a controlled procedure. In addition, the pressurization of the working medium makes it a much better reactor coolant.

The dilemma facing the closed-cycle gas-cooled reactor exponent when he proposes such a system is that the efficiency obtainable at the higher temperatures is certainly very attractive, but how long will it be until these temperatures are realized. The answer to this question, of course, is strictly a matter of experiment, but 1200 F and 30 per cent efficiency certainly seems within reason for the immediate future.

Another feature of the closed-cycle gas-cooled reactor which is as significant as the high efficiency achievable and, for that matter, is a direct consequence of it, is the compact, lightweight system possible. This is of particular importance for marine propulsion units.

The very attractive potential of the closed-cycle gas-cooled reactor justifies pursuing the reactor and turbine development. These two must be treated as a unit, for indeed they are. The author stated that we must be prepared to think in terms of the overall project. For example, if the use of certain gas, such as helium, complicates the turbomachinery development but solves some sticky problems, this course of action must be given full consideration.

Fuel Processing

The paper "Fuel Cycles in Single-Region Thermal Reactors" by Manson Benedict and Thomas H. Pigford, MIT, was concerned with the interrelationships between a nuclear reactor and the processing plants in which its feed is prepared and its spent fuel is reclaimed.

Discussion was focused on reactors in which fissionable and fertile material are charged to a single region of a reactor, irradiated for the same length of time and processed together. In the reactor model employed it was assumed that all fissions are caused by neutrons whose energy is in the thermal or low-energy resonance region. Most of the nuclear power reactors being built today are of this single-region, thermal type. Both the uranium-plutonium and the thorium–U-233 fuel cycles were treated.

The method used in this paper for analyzing the fuel cycles was an extension of one developed by Spinrad, and the principal question to be investigated was: What fraction of the fuel charged to a reactor may be caused to undergo fission before the reactor ceases to be critical?

The answer to this question according to the authors, depends on three main factors. (1) The way the reactor and processing plant are tied together. (2) The way fuel is moved through the reactor. (3) The neutron economy of the reactor. Each of these factors was discussed qualitatively before methods for dealing with them quantitatively were developed.

C. E. Stevenson, Phillips Petroleum Co., reviewed the steps in the chemical reprocessing phase of the nuclear fuel cycle in respect to their significance to a developing nuclear power economy in his paper, "The Fuel Cycle from the Standpoint of the Fuel Reprocessor."

The recovery of unconsumed fuel, and of newly bred fuel or of fertile material discharged from energy-producing nuclear fission reactors appears to be an economic necessity because of the value of uranium, thorium and of the fact that its utilization in reactors must inevitably be quite incomplete per reactor cycle. There are conceivable cases wherein reactors produce energy with a high value such that the cost of unconsumed fuel is negligible relative to that of the overall cycle (for example, those producing power at remote location, or those providing energy for military purposes), but these exceptions are not felt to weigh significantly against the general conclusion that, where the discharged fuel can be obtained without major difficulty, the value of the material left warrants considerable effort and expense to return it to useful channels. Even though certain power reactors may produce economic power without consideration of waste fuel recovery (for example those utilizing uranium of very low enrichment), the discharged fuel elements by themselves constitute a waste of some value. For example, it is almost certain that they will be richer and purer sources of uranium than most ores which presently are laboriously mined and processed. Consequently, it may be assumed that we will in the future be faced with a continuing necessity for devising economic means of recovering nuclear materials from reactors.

Fuel reprocessing must of necessity be a tail on the dog of nuclear power, and it cannot wag independently, but it should exert its influence on reactor design in order that most effective and economic overall cycles may be achieved. The steps in the fuel cycle which are of primary concern to the irradiated fuel reprocessor are shown below:

(1) Aging for heavy isotope decay
(2) Transportation from reactor to process equipment
(3) Preparation of fuel for recovery
(4) Separation of desired products
(5) Isolation and purification of products
(6) Conversion of products to re-usable form
(7) Disposal of wastes or by-products

The preparation of the fuel for recovery may occur either at the reactor or the process facility, or both, and includes mechanical separation of non-fuel materials, can removal, etc. Separation includes removal of products from both fission products and diluent metals, while by isolation it is intended to consider primarily the separation of one product from another (this may not always be necessary). The conversion operations include the preparation of raw materials for refabrication or re-enrichment; i.e., metals, oxides or hexafluoride.

If the aging period is defined by the economics of inventory charges, its length will vary more or less inversely with enrichment, as far as uranium content is concerned. Consequently, there will be a tendency to let normal or slightly enriched materials age for long periods in order to simplify reprocessing, and to promote the development of processing after short cooling and of remote fabrication for more highly enriched materials. However, the plutonium content of discharged fuels will offset this tendency somewhat in that there will be an inventory penalty for not recovering material promptly.

It is obvious that certain reactor reprocessing cycles currently being developed already have as a potential advantage the elimination of the aging period requirement. These include the aqueous homogeneous reactor with continuous bleed stream processing, the liquid metal fuel reactor with its fused salt decontamination scheme, and the sodium-cooled breeder with processing accomplished by high temperature metallurgical-type operations also the fission-recoil separation system proposed by Wolfgang.

The only present experience in transportation of irradiated unprocessed fuel is based on rail and truck transfer of relatively small quantities for purposes where cost was not of major significance. It can confidently be anticipated that actual costs encountered in transfer of power reactor fuels will be significantly different, though it is not so easy to state with assurance that they will be lower. Ton-mile rates must be set by negotiation; the optimum design of suitable heavy-duty high-capacity carriers must be developed; power reactor fuels will undoubtedly be high burn-up materials, and desirably should be transported and processed as soon as possible after discharge. Under such circumstances, an assured means of removing heat from fuel in transit is necessary. Possibilities of water transportation must also be explored, since economics may be such as to dictate location of processing facilities to minimize transportation costs. This would not be the first industry to find that economical transport of feed materials to processing facilities is a major determinant of costs. Safety and security measures required for the bulk transportation of highly

radioactive materials are yet to be resolved completely and may have a significant effect on costs.

There is one feasible way in which transportation costs might be minimized. This involves processing at or near the reactor site, such that carrying charges and investment in carriers are small. However, it now appears that a multiplicity of reactors is required to furnish process materials for an economic processing facility of the present type. Accordingly, this could only be accomplished in connection with a large power reactor complex with capacity in excess of present power stations.

The fuel material as discharged from a reactor may not be most suitable for economic recovery due to the presence of mechanical components associated with it, to protective claddings or cans, or to the presence of reactive coolants. It is important that all possible nonessential components be removed prior to processing since they will add to the bulk material to be handled and shipped, will frequently complicate the chemical operations required, and even if of the same chemical nature as the fuel will add to the volume of material to process and proportionately to the cost. Non-fuel-bearing portions, such as end sections for coolant flow control, can be cut from the fuel elements at the reactor site.

The separation method utilized to recover valuable products from irradiated fuel is the heart of the processing portion of the fuel cycle, and other steps are essentially keyed to it. Separation is used in the sense of providing for partition of nuclear material from other fuel components (alloys, clads, etc.) as well as for decontamination from fission products.

Isolation of individual products may be unnecessary and even undesirable for fuel to be recycled most economically. For example, plutonium may replace uranium-235 in a recycled fuel. Relatively little consideration has been given to processes which would accomplish this most effectively other than by simply omitting the partition step in conventional processes. Similarly, uranium-238 and thorium can be treated in common as producers of fissionable plutonium and uranium-233.

With regard to purification steps required, it should be noted that the specifications of heavy element products which have been established are not necessarily those which are needed for nuclear power fuel recycle.

Present practices involving the storage of large volumes of radioactive process wastes in tanks at remote locations are certainly not going to be an adequate long-term solution to the problem of disposal of long-lived fission products resulting from fuel recycle for a large-scale nuclear power industry. Feasible storage sites are very limited in location and it is doubtful that even specially concentratedwastes be transported economically. Storage vessels will have a finite, even though long, life. Geologic disposal to inaccessible strata cannot be assured as yet, even though the possibilities are certainly worth detailed examination and development. Since it is pretty obvious that the "dispersion and dilution" technique cannot be applied, we must probably look toward "concentration and confinement."

Safety

The first nuclear powered merchant ship is scheduled for completion in 1960. Before this vessel is designed, built, and placed in service careful consideration must be given to the safety aspects of this new source of power. It is clear that the nuclear power plant will present many conditions and requirements which differ from those of the conventional steam and diesel power plants contemplated by existing law and regulations.

The paper, "Development of Safety Standards for Nuclear Propulsion of Merchant Ships" by **Captain Charles P. Murphy,** U. S. Coast Guard, and **Arthur R. Gatewood,** American Bureau of Shipping, described in a general way some of the steps which have been taken toward determining what the problem will be and how to solve them.

When the possibilities of nuclear powered merchant ships began to be seriously considered it became evident very early that many new problems and changed conditions would be presented. In January 1955 the Navy Submarine Nautilus successfully completed her initial sea trials and at the same time questions began to be raised concerning the adaptation of this new power source for use in Merchant Ships.

Just prior to this time, in December 1954, the Ships' Machinery Committee of the Society of Naval Architects and Marine Engineers' Research Committee decided to organize an Atomic Energy Panel. The panel membership was expanded to include members who are familiar with the design, application, construction and operation of nuclear reactors as well as representatives of the shipbuilding and ship operating industries to serve the Coast Guard as an industry advisory group. All of the industry organizations represented in the advisory group have committees working toward uniform and standard practices for nuclear installations which obviously will change as experience develops. After careful consideration the panel thought that they should outline in broad terms their procedure for evaluating reactor designs, but that initial emphasis should be given to defining the broad basic parameters as a guide for evaluating the safety aspects uniquely associated with nulcear power on merchant ships. As developed at the present time this basic frame work is as follows:

A. Vessel situation—
   1. At sea
   2. In restricted waters
   3. At dock side facilities
B. Categories to be studied with regard to applicable vessel situation—
   1. Containment
   2. Shielding and radiation tolerances
   3. Waste disposal
   4. Refueling
   5. Controls
   6. Standby components
   7. Emergency components and equipment
   8. Manning—personnel
   9. Inspection, overhaul, and repair
   10. Operational restrictions.

Beginning with the earliest nuclear reactors, it has been considered to be of primary importance that they be protected against an uncontrolled rise in temperature, whether due to a corresponding uncontrolled rise in neutron level or to a failure of the cooling system. While it is claimed the some types of reactor are intrinsically safe from this kind of accident, it is likely that until a solid background of experience has been acquired, all nuclear reactors will continue to be protected by devices

which "scram" them when such devices foresee a dangerously high temperature. But temperature-sensing devices are too slow as well as too insensitive at low levels to provide protection during startup. Therefore neutron-sensing devices are used. The paper, "Safety Circuit Development at Brookhaven National Laboratory," by **J. E. Binns, W. Lones, D. G. Pitcher,** Brookhaven National Laboratory, and **M. Melice,** Nuclear development Corp. of America, limited itself to that part of the safety system which senses neutrons. Similar principles are applicable as well to other portions of the safety system, such as those which sense temperature, coolant flow.

Safety systems generally are subject to two requirements: (*a*) the frequency of false scrams must be small, (*b*) the frequency of failure of the reactor to scram in spite of a genuine scram signal must be extremely small. It will be recognized that neither can in practice ever be made actually zero. Rather, one is faced with the task of using the various means at his command to reduce each of these numbers to an acceptable value. After first deciding what shall be the acceptable value, and after practical solutions have been studied, the law of diminishing returns may dictate a revision of these estimates.

Instrumentation

No standards exist today for instrumentation adequate to insure health and safety in and around a power reactor. However, it is possible to outline (*a*) the measurements required, (*b*) required ranges and accuracies, and (*c*) classes of intruments and their application. Based on these outlines, instrumentation for a representative power reactor is suggested in the paper, "Health Physics Instrumentation for a Power Reactor," by **G. Hoyt Whipple,** University of Rochester Atomic Energy Project.

The required measurements fall into two broad categories: (*a*) those concerned with external exposure to radiation; and (*b*) those concerned with exposure from radioactive materials which enter the body, that is, with internal exposure.

Once radioative material has entered the body, it is possible to estimate the amount retained by measuring (*a*) the amount excreted, (*b*) in a few special cases, the radon and thoron concentrations in the breath, and (*c*) recently the radiation emitted by the material inside the body with large, whole-body counters, or other special devices.

Consideration of the required ranges of sensitivity for protection measurements starts with the maximum permissible dose rates and concentrations recommended by the National Committee on Radiation Protection and now beginning to appear in various State and Federal regulations. The basic figure throughout these recommendations and regulations is 0.3 roentgen equivalent man per week.

Considering the extremes of time exposure—high dosage, little time, little dosage, high time exposure—for radiation instruments to be used in the plant, it is desirable to have ranges from about 0.4 to 40,000 millirem per hour. It is not, of course, necessary that every instrument have this range of 100,000 to 1, but it will be necessary to have instruments that among themselves can cover this range.

The discussion to this point has been concerned entirely with the measurement of external radiation. A similar, but somewhat less precise line of reasoning indicates the need for corresponding limits for the measurements of air- and water-borne contamination, starting in both cases with the maximum permissbile concentrations recommended by the National Committee on Radiation Protection. In the few cases where levels higher than these upper limits may occur (e.g., the reactor core gas system, and the fuel element decontamination drain), the monitors will not be required to approach within several orders of magnitude of the lower limit.

Waste Control

E. C. Tsivoglou, W. Marcus Ingram, Robert A. Taft Sanitary Engineering Center, and **E. D. Harward,** U. S. Atomic Energy Commission, in a paper entitled "Stream Surveys for Radioactive Waste Control," discussed the organization, planning, and performance of stream radioactivity surveys with examples involving several types of contaminant. Collection methods for three types of stream sample, desirable frequency of sampling, and location of sampling points were considered as well as hydrologic studies. The interpretation and significance of survey results was also discussed.

Every stream radioactivity survey has its own special features, and each problem of stream contamination by radioactive wastes is distinctive. Hence, no two stream surveys for radioactive waste control are likely to be quite the same in detail. As an obvious example, the specific radioisotopes (as, radium, radiophosphorus, fission products) involved in any case will affect the types of sample to be emphasized, types of analysis required, survey duration, etc. If short half-life radioisotopes are involved, a field laboratory may be required. The hydrologic features of each stream are different, and may affect the timing and course of the survey. Usually, the source of waste and the specific radioisotopes of concern will be known in advance. In general, then, each stream survey for radioactive waste control must be planned and executed as an individual problem different from most if not all others.

The three distinct types of stream sample (water, mud, aquatic biota) are all of importance. Each yields information not derivable from the other two, and no one type should be neglected if an adequate interpretation in terms of the extent and effects of stream contamination is desired. Of the three types, the biological samples are perhaps the most difficult to obtain, but in estimating the effects and significance of stream contamination their importance is clear.

The duration of any individual survey will depend especially upon its importance and its major purpose. A great deal of information can be obtained in a brief intensive survey of, say, 10 days, if planning is thorough and complete. On the other hand, seasonal variations of temperature, stream flow, predominant biological species, etc., may be of importance, requiring either an extensive, long survey or a series of briefer field studies. Background radioactivity levels cannot be determined once and thereafter serve for all time, but must be checked regularly and indefinitely in order to follow local and national changes and trends.

American Power Conference Program

THE American Power Conference, sponsored by Illinois Institute of Technology in cooperation with fourteen universities and nine local and national engineering societies, will be held on March 27, 28, and 29, 1957 at the Sherman Hotel in Chicago. It will be the 19th Annual Meeting.

The stated purpose of the conference is to provide a forum for the exchange of information in the fields of power generation, transmission, distribution and utilization.

Wednesday, March 27, 1957, 9:00 a.m. Registration, Mezzanine Floor—Sherman Hotel

10:00 a.m.–12:00 Noon. Opening Meeting—Grand Ballroom

Chairman: Allen Van Wyck, President, Illinois Power Company, Decatur, Ill.

Co-Chairman: W. A. Lewis, Professor of Electrical Engineering, Illinois Institute of Technology, Chicago, Ill.

(a) Invocation. The Reverend Iver G. Lawrence, Chaplain, Illinois Institute of Technology, Chicago, Ill.

(b) The Preference Policy in the Sale of Federal Power. John Jirgal, chairman of the group on Power Generation and Distribution, Second Hoover Commission, Chicago, Ill.

(c) Similarities in the Technical Features of Nuclear Power Development in the United States and Other Countries. Walter Zinn, President, General Nuclear Engineering Corporation, Dunedin, Fla.

(d) The Future of Nuclear Power. Norman H. Hilberry, Deputy Director, Argonne National Laboratory, Lemont, Ill.

12:15 p.m. American Power Conference Luncheon—Bernard Shaw Room. Sponsored by the American Society of Mechanical Engineers

Chairman: R. S. Stover, Vice President, Region VI, American Society of Mechanical Engineers, Marshalltown, Iowa.

Co-Chairman: W. H. Pletta, Chairman, Chicago Section, American Society of Mechanical Engineers, Chicago, Ill.

Speaker: Donald S. Kennedy, President, Edison Electric Institute and President, Oklahoma Gas and Electric Company.

2:00–5:00 p.m. Central Station Steam Generators—Grand Ballroom

Chairman: H. L. Solberg, Head, School of Mechanical Engineering, Purdue University, Lafayette, Ind.

Co-Chairman: J. T. Anderson, Associate Professor of Mechanical Engineering, Michigan State University, East Lansing, Mich.

(a) The Economic Effects of Steam Preheating Combustion Air on Air Heater and Economizer Surfaces. Walter F. Portzline, Design Engineer, Steam Department, Foster Wheeler Corporation, New York, N. Y.

(b) Incorporating the Heat from the Stack Gases into the Supercritical Heat Cycle at Eddystone Station. Samuel A. Arnow, Senior Engineer, Mechanical Engineering Division, Philadelphia Electric Company, Philadelphia, Pa.

(c) Operating Experiences with Twin Furnace Boilers. E. M. Powell, Executive Assistant to the Vice President, Combustion Engineering, Incorporated, New York, N. Y.

(d) Advances in the Field of Large Steam Generators. D. R. Wilson, Assistant Chief Engineer, The Babcock and Wilcox Company, New York, N. Y.

2:00–5:00 p.m. Water Technology I—Assembly Room

Chairman: J. F. Wilkes, Director, Research Development, Dearborn Chemical Company, Chicago, Ill.

Co-Chairman: M. B. Golber, Head Power Plant Engineer, Armour and Company, Chicago, Ill.

(a) An Application of Hot Lime Zeolite to Moderate High Pressure Boiler Operations. Ben Varon, Richfield Oil Company, Los Angeles, California, and S. B. Applebaum, Cochrane Corporation, Philadelphia, Pa.

(b) Operation of a Large Hot Lime Zeolite System for High Pressure Boilers. J. E. Hardin and Glenn Hull, Standard Oil Company of Indiana, Whiting, Ind.

(c) A Survey of Operating Plants, Problems, and Successful Operation. L. F. Wirth, Ion Exchange Division, National Aluminate Corporation, Chicago, Ill.

(d) Prepared discussions.

Evening Forum

TRENDS IN EMPLOYMENT CONDITIONS FOR ENGINEERS

8:00–10:00 p.m. Grand Ballroom.

Sponsored by the Engineers Joint Council

Chairman: Thomas W. Hopper, Chairman, Engineers Joint Council Committee of Employment, Day & Zimmerman, Inc., Philadelphia, Pa.

Co-Chairman: Earl C. Kubicek, Director of Alumni Relations and Placement, Illinois Institute of Technology, Chicago, Ill.

G. Brooks Earnest, President, Fenn College, Cleveland, Ohio.

James D. Esary, Jr., Corporate Manager of Labor Relations, Boeing Airplane Company, Seattle, Wash.

J. F. Larsen, Director, Research Center, Minneapolis-Honeywell Regulator Company, Hopkins, Minn.

William D. Morton, Electrical Engineer, Pennsylvania Power and Light Company, Allentown, Pa.

Charles F. Savage, Jr., Consultant, Professional Relations Engineering Personnel Department, General Electric Company, New York, N. Y.

O. W. Tuthill, Commercial Manager, Merchandising, Illinois Bell Telephone Company, Chicago, Ill.

Discussion.

Thursday, March 28, 1957, 9:00 a.m.–12:00 Noon. Steam Turbines—Grand Ballroom

Chairman: Murray Joslyn, Vice President, Commonwealth Edison Company, Chicago, Ill.

Co-Chairman: R. Clay Porter, Professor of Mechanical Engineering, University of Michigan, Ann Arbor, Mich.

(a) Economics of Higher Pressures and Temperatures for Steam Turbines in Industry. M. M. Patterson, Medium Steam Turbine-Generator and Gear Department and W. B. Wilson, Senior Engineer, Engineering Planning and Development, General Electric Company, Schenectady, N. Y.

(b) Super Pressure Steam Turbines. C. C. Frank, Consulting Engineer, Steam Division, Westinghouse Electric Corporation, Philadelphia, Pa.

(c) Advances in the Field of Large Steam Turbines. C. D. Wilson Chief Turbine Design Engineer, Steam Turbine Dept., Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

9:00–12:00 Noon. Water Technology II—Assembly Room

Chairman: S. F. Whirl, Chairman, Executive Committee, Engineers Society of Western Pennsylvania and Chemical Operating Engineer, Duquesne Light Company, Pittsburgh, Pa.

Co-Chairman: T. J. Hodan, Manager, Water Treatment Division, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.

(a) An Experimental Investigation of Oxygen Hydrazine Reaction Rates in Boiler Feedwater. N. L. Dickinson D. N. Felgar, and E. A. Pirsh, Babcock and Wilcox Company, Research Center, Alliance, Ohio.

(b) Recent Applications Results of the Hydrazine-Sodium Sulfite Combination. Robert Hess, Connecticut Light and Power Company, Hartford, Conn.

(c) Three Years Experience with Hydrazine. M. D. Baker, West Penn Power Company, Springdale, Pa.

(d) Prepared discussions

9:00–12:00 Noon. Hydroelectric Power Development—Louis XVI Room

Chairman: Adolph J. Ackerman, Consulting Engineer, Madison, Wis.

Co-Chairman: D. H. Madsen, Department of Mechanical Engineering, State University of Iowa, Iowa City, Iowa.

(a) Integration of Hydroelectric and Steam Power on the Pacific Gas and Electric System. Walter Dryer, Vice-President and Chief Engineer, Pacific Gas and Electric Company, San Francisco, Calif.

(b) Economics of Power Generation for the TVA System. Robert A. Monroe, Chief Design Engineer, Tennessee Valley Authority, Knoxville, Tenn.

(c) Discussion.

2:00–5:00 p.m. Central Stations—Grand Ballroom

Chairman: K. M. Irwin, Vice President, Philadelphia Electric Company, Philadelphia, Pa.

Co-Chairman: Ben G. Elliott, Chairman, Department of Mechanical Engineering, University of Wisconsin, Madison, Wis.

(a) Turbines, Condensers and Feedwater Heaters and the Laboratories that Make Them Possible. M. L. Mochel, Westinghouse Electric Corporation, South Philadelphia Works, Philadelphia, Pa.

(b) Recent Progress in the Field of High Pressure, High Temperature Power Generation in Great Britain. J. W. H. Dore, Generation Design Branch, Central Electricity Authority. London, England.

(c) Future of the Steam Cycle. C. W. Elston and J. E. Downs, Large Steam Turbine-Generator Department, General Electric Company, Schenectady, N. Y.

2:00–3:30 p.m. Water Technology III—Assembly Room

Chairman: M. D. Baker, First Vice Chairman, Joint Research Committee and Chief Chemist, West Penn Power Company, Springdale, Pa.

Co-Chairman: Selden K. Adkins, Manager, Consulting Service, National Aluminate Corporation, Chicago, Ill.

(a) Report of ASME Joint Research Committee. P. B. Place, Chairman, Joint Research Committee, West Penn Power Company, Springdale, Pa.

(b) Counterflow Regeneration of Deionizers. Paul H. Caskey, Illinois Water Treatment Company, Rockford, Illinois and T. P. Harding, Chief Chemist, Omaha Public Power District, Omaha, Neb.

(c) Anion Exchange Sub-Fill as a Factor in Rinse Requirements of Demineralizers. R. Dvorin, and J. H. Duff, Graver Water Conditioning Company, New York, N. Y.

2:00–5:00 p.m. Fuels—Crystal Room

Chairman: Louis C. McCabe, President, Resources Research, Incorporated, Washington, D. C.

Co-Chairman: Martin Elliott, Director, Institute of Gas Technology, Illinois Institute of Technology, Chicago, Ill.

(a) Pipeline Transportation of Coal. Clarence A. Dauber, director of civil and mechanical engineering, Cleveland Electric Illuminating Co., Cleveland.

(b) Bituminous Coal Market in the Immediate Future. George S. Lamb, manager Business Service, Pittsburgh Consolidation Coal Co., Pittsburgh.

(c) Discussion

3:30–5:00 p.m. Water Technology IV—Assembly Room

Co-Chairman: W. R. Homan, Chief Chemist, Commonwealth Edison Company, Chicago, Ill.

(a) Aluminum Condenser Tubes—Report on a Plant Installation.

W. A. Pollock, Wisconsin Electric Power Company, Milwaukee, Wis.

(b) Prepared Discussions: R. A. Wilson, Allis-Chalmers Manufacturing Company, Milwaukee Wisconsin and Ellis Verink, Aluminum Company of America, New Kensington, Pa.

(c) Method of Measurement and Recording of Small Concentrations of Oxygen Dissolved in Water. M. W. Greene and R. W. Negus, Arnold O. Beckman, Incorporated, South Pasadena, Calif.

Friday, March 29, 1957, 9:00–12:00 Noon. Industrial Power Plants—Grand Ballroom

Chairman: F. G. Feeley, Jr., Olin Hydrocarbon Chemicals Div., Olin Mathieson Chemical Corporation, New York, N. Y.

Co-Chairman: Chester R. Earle, Executive Editor, Power Engineering, Chicago, Ill.

(a) A New Combined Steam-Gas Turbine Industrial Power Plant. W. B. Wilson, Senior Engineer, Economic Studies, Engineering Planning and Development, General Electric Company, Schenectady, N. Y.

(b) Distribution of Steam and Electrical Power Costs in an Industrial Plant. H. P. Kallen, Associate Editor, Power, New York, N. Y.

(c) Incremental Efficiency Testing of Industrial Turbine Generators to Determine Steam Rates and Valve Points Saves Kilowatts. Gerald L. Decker, Superintendent of Operation, Power Department, Dow Chemical Company, Midland, Mich.

(d) Precision Valve Point Loading of Turbines Using a Digital Computer saves Dollars. Aaron D. Brooks, Technical Expert, Engineering Department, Dow Chemical Company, Midland.

9:00–12:00 Noon. Condenser and Feedwater Circuit—Assembly Room

Chairman: M. P. Cleghorn, Professor of Mechanical Engineering, Iowa State College, Ames, Iowa.

Co-Chairman: Roy Sahlstrom, Faville-LeVally Corporation, Chicago, Ill.

(a) Developments Covering Welding of Non-Ferrous Tubes in Steam Surface Condensers. R. A. Wilson, Consulting Engineer, Heat Transfer and Water Conditioning Department, Allis-Chalmers Manufacturing Company.

(b) Fundamental Need for Welding Non-Ferrous Tubes Into Feed Water Heaters. George A. Worn, Consultant to Heat Exchanger Division, The Lummus Company, New York.

(c) Progress Report on High Speed Boiler Feed Pumps. I. J. Karassik, Assistant to the Vice President and Consulting Engineer, and T. W. Edwards, Manager, Boiler Feedpump Section, Harrison Division, Worthington Corporation, Harrison, N. J.

(d) Boiler Feedpumps for 6500 psi Discharge Pressure. Hans Hornshuch, Chief Development Engineer, Centrifugal Machinery, Ingersoll Rand Company, Phillipsburg, N. J.

9:00–10:30 a.m. Digital Computers for Mechanical Problems—Louis XVI Room

Chairman: Gerald V. Williamson, Vice President, Production and Distribution, Union Electric Company, St. Louis, Mo.

Co-Chairman: Reno C. King, Associ-

ate Professor of Mechanical Engineering, New York University, New York, N. Y.

(a) The Use of Digital Computers for Piping Flexibility Calculations. T. Kolflat, Mechanical Engineer, and K. E. Knapp, Mechanical Engineer, Sargent & Lundy, Engineers, Chicago, Ill.

(b) Generalized Heat Balance Computation on the IBM Type 650. Robert K. Large, Machine Computation Section, Detroit Edison Company, Detroit, Michigan and J. E. Gerngross, Analytical Engineering Section, General Electric Company, Schenectady, N. Y.

2:00–5:00 p.m. Nuclear Energy—Grand Ballroom

Chairman: Richard F. Humphreys, Assistant Director, Armour Research Foundation, Chicago, Ill.

Co-Chairman: A. H. Barnes, Director, Reactor Engineering, Argonne National Laboratory, Lemont, Ill.

(a) Inter-American Progress Toward Economic Nuclear Power. Walter F. Friend, Nuclear Engineering Consultant and Leonard F. C. Reiche, Nuclear Engineering Director, Ebasco Services Incorporated, New York, N. Y.

(b) Significant Developments in Large Boiling Water Reactor Plants. Raymond C. Freeman, Manager, Engineering Section, Atomic Power Equipment Department, General Electric Company, San Jose, Calif.

(c) PAR Homogeneous Reactor Project—Plant Design and Operating Problems. W. E. Johnson, PAR Project Manager, D. H. Fax, Assistant to PAR Project Manager, Commercial Atomic Power Activities, Westinghouse Electric Corp., and S. C. Townsend, Manager, Atomic Power Dept., Pennsylvania Power and Light Co., Allentown, Pa.

(d) A New Approach to the Design of Containment Shells for Atomic Power Plants. Alf Kolflat, Senior Partner and W. A. Chittenden, Atomic Power Engineering Group, Sargent & Lundy, Engineers, Chicago, Ill.

9:00–12:00 Noon. Gas Turbines—Grand Ballroom

Chairman: Peter R. Broadley, Director, Locomotive Development Committee, Bituminous Coal Research, Incorporated, Dunkirk, N. Y.

Co-Chairman: Warren E. Ibele,

Department of Mechanical Engineering, University of Minnesota, Minneapolis, Minn.

(a) An Operator's Evaluation of the Versatile Gas Turbine. George H. Krapf, Division Superintendent, and H. J. Gifford, Supervisor of Technological Coordination, Power Production Division, South Works, United States Steel Corporation, Chicago, Ill.

(b) Operating Experiences on Gas Turbine Power Generation Plants. J. O. Stephens, Manager, Development and Project Section, Gas Turbine Engineering, Westinghouse Electric Corporation, South Philadelphia, Pa.

(c) Design and Characteristics of a Combined Gas and Steam Cycle for a 40,000 kw Unit. A. R. LeBailly, Partner, and L. Skog, Jr., Associate, Sargent & Lundy, Engineers, Chicago, Ill.

(d) Economics of Small Supercharged Plants. E. L. Richardson, General Electric Company, Boston, Massachusetts, and E. L. Damin, Foster Wheeler Corporation, New York, N. Y.

2:00–5:00 p.m. Symposium on Computers and Network Analyzers—Crystal Room

Chairman: H. L. Garbarino, Assistant Chairman, Electrical Engineering Research Department, Armour Research Foundation, Chicago, Ill.

Co-Chairman: James E. Van Ness, Associate Professor of Electrical Engineering, Northwestern University, Evanston, Ill.

(a) Application and Technical Uses of Digital Computers. Leonard W. Swanson, Manager in Charge of Operations Research, Arthur Andersen and Company, Chicago, Ill.

(b) The Role of an Independent Computating Facility in Power Systems Engineering. R. B. Wise, Associate Engineer, Armour Research Foundation, Chicago, Ill.

(c) Potential Computer Applications in a Power Company. L. E. Jensen, T. W. Schroeder and G. P. Wilson, Illinois Power Company, Decatur, Ill.

(d) Relation of Digital and Analog Computers in the Solution of Power Systems Problems, David B. Breedon and Ray W. Ferguson, Westinghouse Electric Corporation, East Pittsburgh, Pa.

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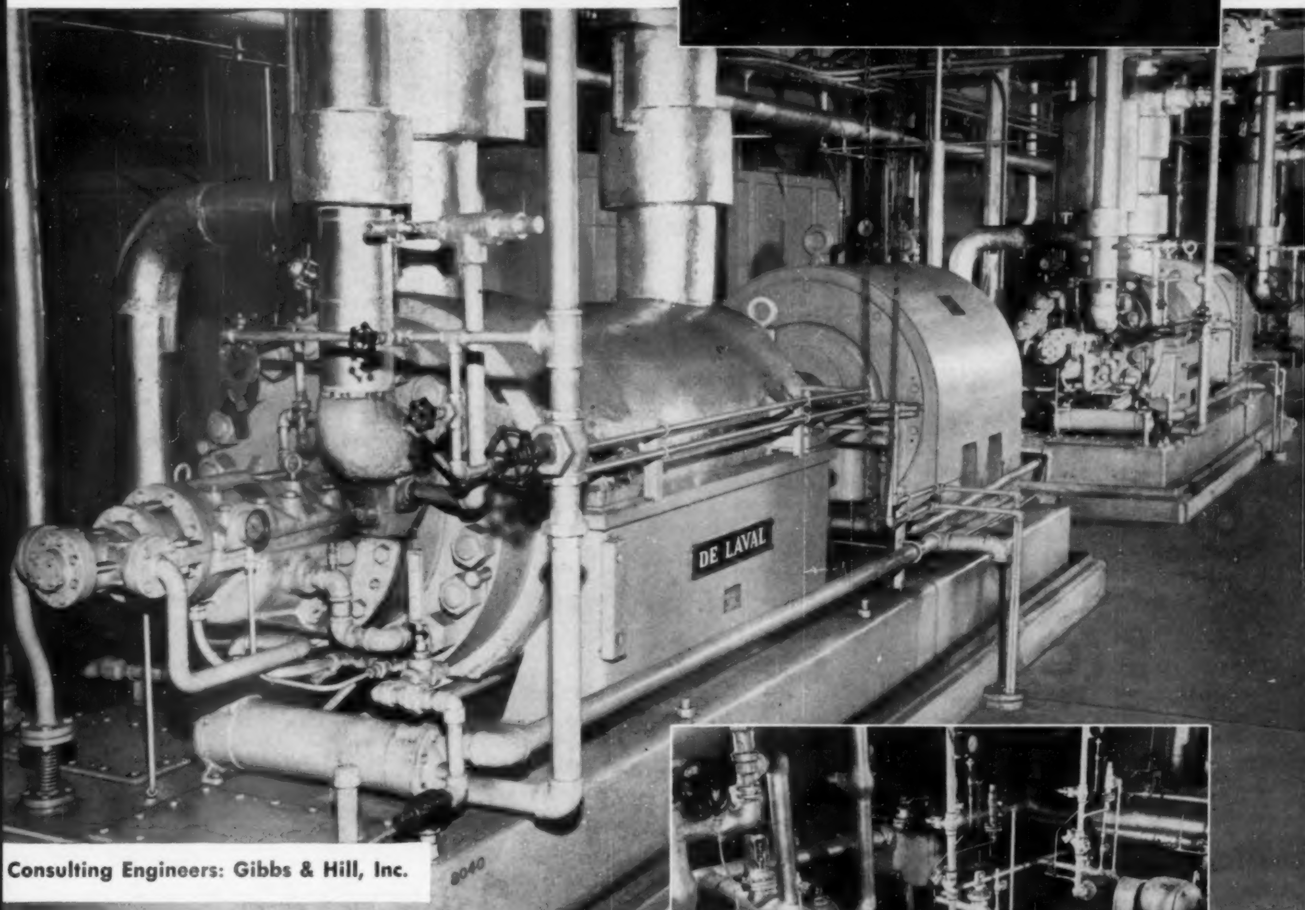

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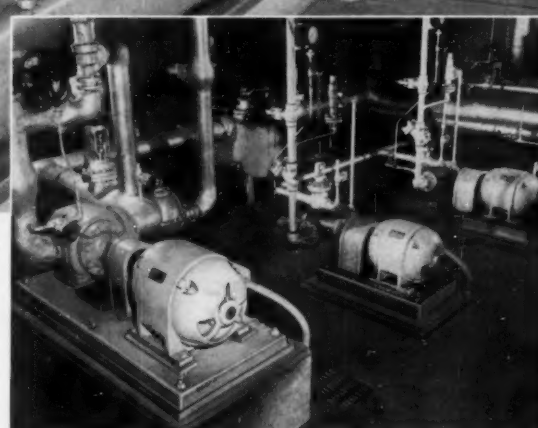

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